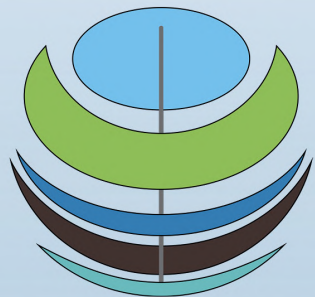


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Paleolimnology
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2022, № 4

- > abiotic and biotic water components;
- > ecosystem-level studies;
- > systematics and aquatic ecology;
- > paleolimnology and environmental histories;
- > laboratory experiments and modeling

Paleoreconstruction of environment of Northern Eurasia during the Pleistocene-Holocene inferred from lake sediment proxies

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From September 5 to 10, 2022, the 5th International Conference and School of Young Scientists “Paleolimnology of Northern Eurasia” was held in St. Petersburg on the basis of the Herzen State Pedagogical University of Russia and the Russian Geographical Society, dedicated to a wide range of scientific and methodological issues of paleolimnological research on the vast territory of the northern part of the Eurasian continent.

The conference “Paleolimnology of Northern Eurasia” is devoted to the reconstruction of the dynamics of the climate and environment of Northern Eurasia in the Pleistocene and Holocene on the basis of multidisciplinary studies of lake bottom sediments and reconstruction of paleobassins by geomorphological and geoarchaeological methods. The conference allowed the scientific community to exchange new knowledge and experience in the field of paleolimnology.

Training seminars were held for young scientists, postgraduates and students. The International Paleolimnological Conference is held regularly every two years alternately in the European and Asian parts of Russia on the basis of Universities and Research Centers of the Russian Academy of Sciences. Previous conferences were held in Petrozavodsk (Northern Water Problems Institute of the Karelian Scientific Center of the Russian Academy of Sciences, 2014), in Yakutsk (Northeastern Federal University, 2016), in Kazan (Kazan (Volga Region) Federal University, 2018) and in Irkutsk (Limnological Institute of the Siberian Branch of the Russian Academy of Sciences, 2020).

New results in paleoreconstruction reported in the 5th International Conference have been published by 88 short communications in special issue. The geography and subject matter of the articles are extensive. Communication are presented from Herzen State Pedagogical University of Russia, Saint-Petersburg State University, Institute of Limnology Russian Academy of Science, North-Eastern Federal University of Yakutsk, A.P. Karpinsky Russian Geological

Research Institute, Arctic and Antarctic Research Institute, Institute of Geography Russian Academy of Science, Moscow State University, Northern Water Problems Institute of the Karelian Research Centre, Kazan (Volga region) Federal University, Institute of Geology of the Karelian Research Centre of the Russian Academy of Sciences, Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Science, A.P. Vinogradov Institute of Geochemistry Siberian Branch of the Russian Academy of Sciences, National Research Irkutsk State Technical University, A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences, Novosibirsk State University, Ilyichev Pacific Oceanological Institute of Russian Academy of Science, Yuzuncu Yil University (Van, Turkey), N. Laverov Federal Center for Integrated Arctic Research of Ural Branch of the Russian Academy of Sciences, Fersman Mineralogical Museum, Novgorod State University, Tomsk State University, Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Research Unit Potsdam, A.P. Karpinsky Russian Geological Research Institute (VSEGEI), Institute of Soil Science and Agrochemistry, Siberian Branch of the Russian Academy of Science, South Urals Federal Research Center of Mineralogy and Geoecology of the Urals Branch of the Russian Academy of Sciences, Institute of Volcanology and Seismology, Far East Branch of the Russian Academy of Science, GEOMAR Helmholtz Center for Ocean Research Kiel, Shirshov Institute of Oceanology of Russian Academy of Sciences, Perm State University, North-East Interdisciplinary Scientific Research Institute Far East Branch Russian Academy of Sciences, Geological Institute of Russian Academy of Sciences, Lakehead University Orillia (Canada), Geological Institute of Kola Science Center Russian Academy of Science, Institute of Monitoring of Climatic and Ecological Systems of Siberian Branch of the Russian Academy of Sciences, Institute of Water and Ecological Problems Far East Branch of the Russian Academy of Science, Institute

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of Biophysics Siberian Branch of the Russian Academy of Sciences, Institute of Archaeology and Ethnography of Siberian Branch of the Russian Academy of Science, Institute of Tibetan Plateau Research, Key Laboratory of Alpine Ecology, Chinese Academy of Sciences (Beijing, China), CAS Center for Excellence in Tibetan Plateau Earth Sciences, Chinese Academy of Sciences (CAS) (Beijing, China), Darwin State Nature Biosphere Reserve, Institute of the Earth's Crust of Siberian Branch of the Russian Academy of Sciences, Swiss Federal Institute of Aquatic Science and Technology EAWAG (Switzerland), Tyumen Scientific Centre of Siberian Branch of the Russian Academy of Sciences, Institute of Physicochemical and Biological Problems of Soil Science of the Pushchino Scientific Centre for Biological Research of the Russian Academy of Sciences, Institute of Geology of the Dagestan Scientific Centre of the Russian Academy of Sciences, Institute for Nature Management of the National Academy of Sciences of Belarus, Belarusian State University and others.

The topics of the reports vary from narrowly focused on the objects and subjects of research to broad and deep generalizations. More than half of the reports are presented by young researchers. The presented results of multidisciplinary, paleolimnological studies of recent years show that this scientific direction is actively developing in Russia and abroad, that there is an expansion of the scientific paleolimnological community, requiring the creation of the Eurasian Paleolimnological Association (EAPA).

Acknowledgements

We are grateful to all of the authors who contributed to this special issue, reviewers of all the papers. This special issue stems from presentations made at 5th International Conference on Paleolimnology of Northern Eurasia, from 05 to 10 September 2022, , Saint-Petersburg, Russia.

Short communication

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Geomorphological evidence of Lake Ladoga Holocene regressions after the Baltic Ice lake drainage (derived from sediment echosounder data)

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ABSTRACT. Lake Ladoga has been experiencing frequent water-level fluctuations during the Holocene. Plenty surveys about reconstructions of lake level were published during the last century. They focused on the onshore transgressive sediments and landforms, while a regression below present level was only an assumption. Here for the first time, we present indications of lake-level lowstands by means of sediment echosounder data collected within the "PLOT-project". Three types of landforms of coastal and terrestrial origin are detected in the basin. These are coastal bars, erosional terraces and buried erosional valleys. Three paleo-shorelines were determined at depths of 13, 21 and 40-42 m. The first two shorelines are identified by the presence of the coastal bars, while the level of maximum regression is obtained from erosional marks. Reported landforms are assumed to be formed in the Early Holocene following the Baltic Ice Lake drainage.

Keywords: Lake Ladoga, the Holocene, the Postglacial, water-level fluctuations, paleo-shorelines, lacustrine geomorphology

1. Introduction

It was assumed, that lacustrine sedimentation in Lake Ladoga began formed following the Baltic Ice lake (BIL) drainage during the Late Pleistocene-Holocene transition (Gromig et al., 2019). It is considered that the basin was isolated and experienced a major regression after this event. Afterwards, it occurred several Holocene transgressive-regressive phases detected in onshore (Kvasov et al., 1990). However, there were no studies of regression marks in the basin. Abramova et al. (1967) proposed that paleo-shorelines of maximum regression might be detected at a depth of 55 m (50 m below sea level (b.s.l.)). Subetto et al. (1998) assumed the regression at the level of 45 m (40 m b.s.l.). The goal of this research is to identify landforms of lake lowstands and level at maximum regression.

2. Materials and methods

Hydroacoustic data obtained by Innomar sediment echosounder in the frame of the Russian-German project "PLOT" were used in this study. The IHS Kingdom Software was used for data proceeding.

To calculate depth values two-way travel-time was converted using a velocity of 1600 m/s. Depth values are presented in meters below lake level (i.e. + 5 m a.s.l.).

3. Results

Two seismic units were defined. According to Lebas et al. (2021), we correlate them to Late Pleistocene glacial lacustrine sediments, mostly varved clays (the lower unit) and Holocene lacustrine sediments presented by silts, muds and sands (the upper unit).

Three types of landforms were identified in the central and the southern parts of the lake. At depths of 13, 21 and 41 m some ridges similar with coastal bars are recognized (Fig. 1). Figure. 1A shows clear prograding reflectors and sediment tail at the distal part of the bar. Its altitude is 3 m, while length is 1120 m. Underneath the bar a lens-shaped body was identified. We assume that the sediments was presented by buried lagoon gyttia and peat. It seems that this bar was formed during a transgressive-regressive cycle.

At the southern flank of the Konevets ridge another bar was observed at the 40-41 m depth (Fig. 1B),

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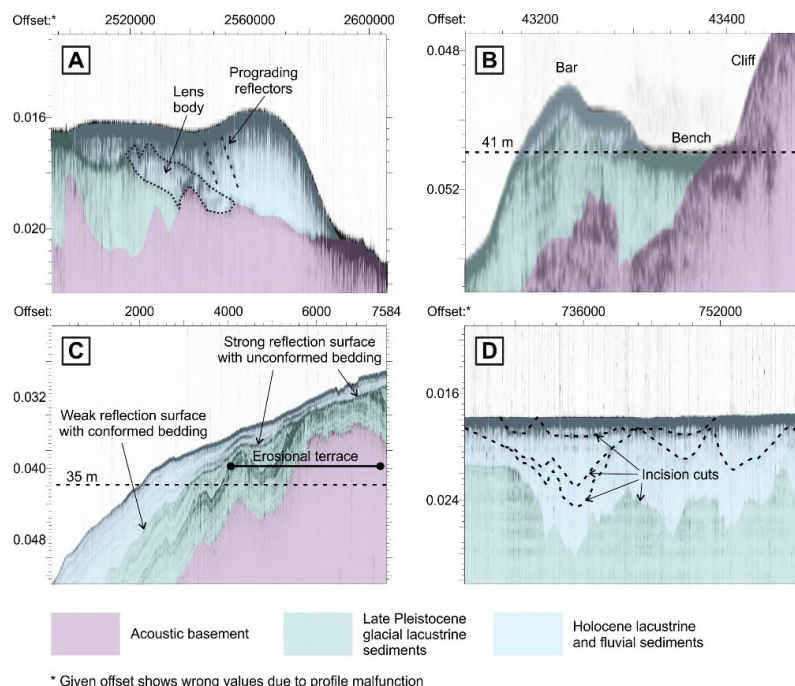


Fig.1. Examples of different bedforms derived by the echosounder data. The upper scale shows offset (m), the left scale is a two-way-time (s). A – a coastal bar at the southern part of the lake. B – an erosional platform, including cliff, bench and coastal bar. Southern slope of the Konevets ridge. C – an erosional terrace buried under the Holocene sediments. The southwestern slope of the Mantsinsaari ridge. D – an erosional valley with 4 incision cuts at the mouth of the Petrokrepost bay.

but with smaller proportions (1 m high and 76 m long). The erosional platform with bench and cliff are also witnessed at this section.

Erosional terraces were another type of landforms. These features were situated on the eroded surface of the Late Pleistocene deposits and was mostly buried by the Holocene sediments. They are characterized by strong reflection surface crossing layering of varved clays (Fig. 1C). Mostly, they are distributed in the SE littoral zone, on flanks of the Mantsinsaari ridge and at the foothills of moraine ridges (central part of the lake).

Erosional valleys were identified at the mouth of the Petrokrepost bay (13-21 m deep) cutting the Late Pleistocene sequences (Fig. 1D). Their erosional basis reaches up to 30 m depth. There are three valleys with multi-thalweg, saw-shaped cross-profile. Four erosional surfaces were detected.

4. Discussion and conclusions

Different types of landforms reflecting subaerial conditions of formation were reported here. We assume that the presented features were formed during the Early Holocene. This is supported by the assumption that lake level after the Ancylus transgression was never lower than present (Sheetov, 2007). So, the only period of the Holocene when they could have formed is following the BIL drainage (the Yoldia stage at the Baltic sea).

Three coastal bars are identified at 13, 21 and 41 m below modern lake level. These are clear indicators of Lake Ladoga paleo-shorelines.

The maximum depth of erosional terraces varies widely. We divide these landforms into 3 groups relating to their maximum depth and spatial distribution: 34-35,

41-42 and 58-64 m. We suppose that 41-42 m should be accepted as the level of the deepest regression. The 34-35 m erosional marks are located at Mantsinsaari flanks (northern part of the lake), consequently they might be related to tectonic uplift. The 58-64 m group is marked at the foothills of the moraine ridges with steep slopes, thus gravity processes might have affected their formation.

The erosional valleys crossing the Late Pleistocene sediments were also identified in the central part of the basin by Lebas et al. (2021) and were interpreted as channels of glacial meltwater discharge. However, our valleys are located in the southern shallow water area. Considering that they erode the varved clays of the BIL, which stopped accumulating when the ice sheet located at the Salpausselkä II moraine. It is highly unlikely that meltwater effluxes reached this area. Thus, we believe that these valleys was fluvial origin. Several rivers flow into the Petrokrepost bay at present, so the valleys might connect with them. Moreover, basing on the assumption that the Paleo-Mga River entered into the lake before the Ladoga transgression (Ailio, 1915), we may assume that one of the valleys could represent the Paleo-Mga valley.

Four incisions were documented, suggesting that the lake experienced several fluctuations. Multiple thalwegs are evidence of stabile and continuous water supply with channel migration.

To sum up, the following conclusions are drawn:

1. Coastal bars, erosional terraces and erosional valleys were identified in the basin of Lake Ladoga;
2. Age of their formation correlates to the Late Pleistocene-Holocene transition, when the BIL drained out and Lake Ladoga became isolated;

3. Three shorelines were identified – 16, 21 and 41 m, where 41 m is associated with the maximum regression level;
4. The regression was not smooth and experienced several minor oscillations.

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Conflict of interest

The authors declare no conflict of interest.

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Evolution of the coastal Pitsunda Peninsula (Republic of Abkhazia) during Late Holocene

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ABSTRACT. The article presents the results of field research on the Pitsunda Peninsula in January-February 2022. Based on the data obtained, the scheme of coast development proposed by Balabanov (2009) is supplemented. The use of modern methods made it possible to clarify the topography, and drilling data formed the basis for reconstruction for the ancient period.

Keywords: palaeolagoon, Pitsunda Peninsula, marine terraces, palaeoreconstruction, Late Holocene

1. Introduction

Since 1970s the Holocene marine terraces of the Pitsunda Peninsula were introduced to intensive economic development and usage. But the fundamental studies, which focused on the palaeogeographic conditions of the coastal area, are needs to be supplemented. Therefore, our main goal is the adjustment of previously published reconstructions of the coasts on the southwestern part of the Pitsunda Peninsula, in particular correction age and morphology evolution of marine terraces. Balabanov (2009) describes the most fully history of the natural topography, however the published data have “gaps” in the current state-of-the-art. These “gaps” were filled up as a result of our research.

2. Materials and methods

Our research based on the previously published data (Balabanov, 2009) and our field materials. We used the UAV and orthophotos, taken from the remote sensing catalog in the public domain and in the field; open access topographic materials; deep coring data and maps of Quaternary deposits, geological, geophysical, magnetic exploration, etc. from the GEOLFOND database.

In the field we used the following methods:

- geomorphological mapping
- aerial photography (UAV)

- hand-coring and sampling. The hand-coring was taken along the supposed boundary of the palaeolagoon. The well material was selected for radiocarbon and diatom analyzes, which had processed in the Institute of Geography RAS.
- topographic and geomorphological profiling using a GNSS instrument (DGPS, RTK). Thus, we have marked the morphometry and boundaries of landforms and their exact location.

3. Results

The results of the work are:

- geomorphological map of the southwestern part of the Pitsunda Peninsula;
- map of the morphodynamics of the Pitsunda Peninsula shores in the Late Holocene;
- schemes (maps) of palaeolandforms of the southwestern Pitsunda Peninsula, including palaeolagoons.

We have described 2 beach-ridge systems. The first (more ancient) one consists of three largest shore shafts with NW-SE reach. These landforms predetermine the forming of Pitsunda Peninsula and its palaeolagoon. The second beach-ridge system consist of 15 shore shafts with SW-NE reach, which filled the palaeolagoon.

Drilling allowed us to estimate the intensity of

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transformation and filling of the palaeolagoon. We assume that in ancient times, when the city of Pitius existed on the shores of the peninsula, palaeolagoon could serve as a seaport. Thus, the drilling data allowed us to take another look at the controversial issue of shipping opportunities.

4. Discussion

The chosen palaeolagoon is not the only one on the Pitsunda coast. However, it is the largest such form in the area. Also, this palaeolagoon is located in the territory of intensive economic development, so it has enough good quality data (satellite images, topographic maps, etc.) for our study. We have used modern technologies, so our data is reliable for approving and correction of previously published one.

The authors' drilling data do not cover the entire and sufficient area of the palaeolagoon. The data are scattered and must be correlated; therefore, it is impossible to determine the discrepancies with the data of previous years with absolute accuracy, but it is enough to achieve the aim of the work.

However, the results allow us to fulfill 2 main objectives of the study:

- reconstruction of the spatial positions of the coastlines and comparison with those carried out by Balabanov (2009);
- reconstruction of the sea level changes.

5. Conclusions

- A variant of the palaeogeographical development of the coast of the Pitsunda Peninsula is proposed.
- The existing maps of the evolution of the coastal landforms of the Pitsunda Peninsula have been refined: ancient coastal ridges have been added, the boundaries of the palaeolagoon have been marked
- The boundaries of the palaeolagoon are clarified in the southwest of the Pitsunda Peninsula.
- The patterns of development of the Black Sea basin and its coasts during the transgressive and regressive epochs of the Holocene are confirmed.

Conflict of interest

Authors declare no conflict of interest.

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Short communication

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Tver proglacial lake (Tver region, Russia): myth or reality

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ABSTRACT. In this study we aimed to find a Tver proglacial lake in the Upper Volga low land at the Late Valdai that it have been reconstructed by D.D. Kvasov. Our field studies did not verify previously reconstructed lake terraces at 135 – 140 and 120 – 125 m a.s.l., though at 140 m a.s.l. we found the Volga River terrace near Seslavie (Tver region, Russia). According to OSL data from this terrace, the Volga River has existed in the Upper Volga lowland ever since the LGM.

Keywords: proglacial lake, Volga River, river terrace, OSL-dating

1. Introduction

D.D. Kvasov (1975) reconstructed the Tver proglacial lake as part of the Upper Volga proglacial lake system. This proglacial lake occupied a vast depression from Yakshino village (located between Staritsa and Tver, Tver region, Russia) to Kaliazin (Yaroslavl region, Russia). Kvasov (1975) suggested that the Late Valdian ice sheet dammed the northward-flowing Volga River, which led to the formation of proglacial lakes in the Volga River basin, including the Tver proglacial lake. This lake's drainage channel was located in a valley near Pereslavl-Zalessky; the height of runoff threshold was 140 – 145 m a.s.l.

In the Volga River valley, N.E. Dik (1938) first described a terrace on 135 – 140 m a.s.l., and Kvasov (1975) later proposed that this terrace could be marks of the highest lake level stand. Kvasov also wrote that accumulation of lacustrine sediments in Tver proglacial lake was limited due to its shallow depth. Another river terrace was described by A.I. Spiridonov (1938) at 120 – 125 m a.s.l. Kvasov (1975) was attributed it to a lake terrace of a lower lake level stand. This lake was smaller and occupied only the Kimry-Kaliazin Volga area. The lake's drainage occurred through the present-day Volga River channel.

However, in recent years we were able to collect new data that to casts doubt on the existence of such large proglacial lakes in the Upper Volga Lowland in the Late Valdai (Utkina, 2017; 2020; Panin et al., 2020; 2022)

2. Materials and methods

Field studies were carried out in the Volga River valley near the Seslavie village (about 40 km

upstream from Tver), a few kilometers downstream from Yashkino village – the maximum distribution of the Tver proglacial lake. Outcrops and boreholes were made using the Pride Mount 80 mechanical corer; their location was predetermined by using information from Russian geological foundation's archives. In addition, field studies near Kablukovo (25 – 30 km downstream from Tver) on 132 – 136 m a.s.l. surface and in Novoselki (near Uglich, Yaroslavl region) on 120 m a.s.l. surface were also carried out. OSL dating of two samples was conducted in the Nordic Laboratory for Luminescence Dating at Risø, Denmark.

3. Results

The Volga River near Seslavie has a valley with an obvious terrace staircase (Fig. 1). The highest terrace is located at 139 – 141 m a.s.l., the same as the proglacial lake terrace position as suggested by Kvasov (1975). This terrace consists of medium sand with pronounced basal facies in the bottom. We interpret these sediments as alluvial deposits. OSL dating of two samples collected from sediments of this terrace report ages of 21.1 ± 1.2 ka (Risø-198632) and 20.4 ± 1.3 ka (Risø-198633). The Volga River valley near Seslavie in some cases has steep slope with a pronounced edge above the highest terrace. Possibly, that led Kvasov to thinking that the edge of this slope is the Tver proglacial lake shoreline.

The relief of the 132 – 136 m a.s.l. surface near Kablukovo (25 – 30 km downstream from Tver) is hilly. Our field studies (Baranov, 2021) show that sediments that comprise this surface consist of brown-red and grey loam with pebbles. We interpret these deposits as glacial (till). Sometimes a thin layer of aeolian pale silt covered them. No lacustrine deposits of proglacial lake were found on this surface.

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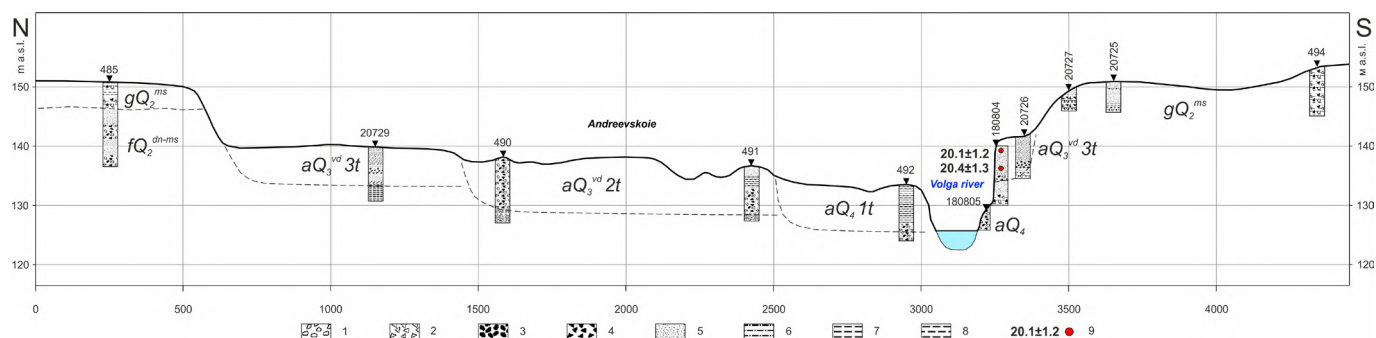


Fig.1. Cross section through the Volga River near Soslavie village.

Legend: 1 – pebbles, 2 – rubbles, 3 – gravel, 4 – gruss, 5 – sand, 6 – loamy sand, 7 – silt, 8 – loam, 9 – OSL data.

A hilly relief also characterizes the 120 m a.s.l. surface in Novoselki (near Uglich). It is comprised by pale silt with a thickness of 1 – 1.5 meters. Red-brown loam with gravel, pebbles and boulders (till) was found underlying these sediments.

4. Discussion and conclusions

We were unable to locate the high lake level terrace on 135 – 140 m a.s.l. in the Upper Volga lowland. Geological structure of boreholes and outcrops studied at this level tells us that these landforms are of different genesis. In Soslavie area, the studied landform was found to be a river terrace formed (as established by OSL) in the LGM. Near Kablukovo, we studied an interfluvial area of glacial plain without a trace of large proglacial lake existence. We can therefore conclude that the Volga River has drained the Upper Volga lowland since the LGM.

In case if the waters of Tver proglacial lake lower level stand (120 – 125 m a.s.l.) drained in the direction of the present-day Volga River, lacustrine deposits must be accumulated somewhere near Uglich. However, geological studies of hypothetical lake terrace located at 120 m a.s.l. in Novoselki found no trace of lacustrine deposits. Geomorphological data says that it is an interfluvial glacial surface.

Thus, based on our data we can establish that:

1. the Tver proglacial lake did not exist at levels of 140 – 145 m a.s.l. and 120 – 125 m a.s.l. in Upper Volga lowland;
2. the Volga River has drained the Upper Volga lowland since the LGM.

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Conflict of interest

Authors declare no conflict of interest.

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Quaternary and geomorphological features of Lake Onego. Comparison with Lake Ladoga

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ABSTRACT. Lake Onego is a very important source of fresh water and traffic artery of Russian NW. In addition, it is a very significant source of paleogeographical and Quaternary geological information. Studies of geology, geomorphology, paleolimnology and ecology of Onego and Ladoga lakes are being conducted since 19th century by different institutes and research companies. At the modern stage of limnological research the most significant research centers are: Saint-Petersburg state university, Moscow state university, Limnological institute RAS, Northern Water problem institute RAS, PMGRE, VSEGEI, VNII Ocenegeologia, and a lot of organizations with geology, ecology, limnology and hydrology specializations with Russian and foreign researchers. This article was written based on the results of field works conducted in 2014 - 2020. The article aimed to update the stratigraphy of Quaternary deposits of the Lake Onego bottom; describe bottom sediments and relief of Lake Onego; highlight stages of the Lake Onego bottom development according to geological and geomorphological features; compare Onego and Ladoga lakes' bottom sediments and relief.

Keywords: Quaternary geology, geomorphology, paleolimnology, bottom sediments, largest European lakes

1. Introduction

Lakes attract different researchers because it is significant source of information about modern nature conditions and paleoenvironment of region. Speaking of Russian North-West (NW), the biggest lakes of this region are Ladoga and Onego. In this work, maps of Quaternary sediments, geomorphological features and conditions of Ladoga and Onego lakes have been highlighted.

2. Materials and methods

Works carried out in Lake Onego included bottom sampling and geophysical research. Bottom sampling was carried out with gravitation corer (3 meters length) and vaan-ween bucket. Geophysical research included seismoacoustic profiling. The work resulted in more than 40 samples of bottom deposits and more than 800 kilometers of seismic profiles. After field works, dating and palinological and geochemical research were performed. Figure 1 shows sampling stations and seismic profiles.

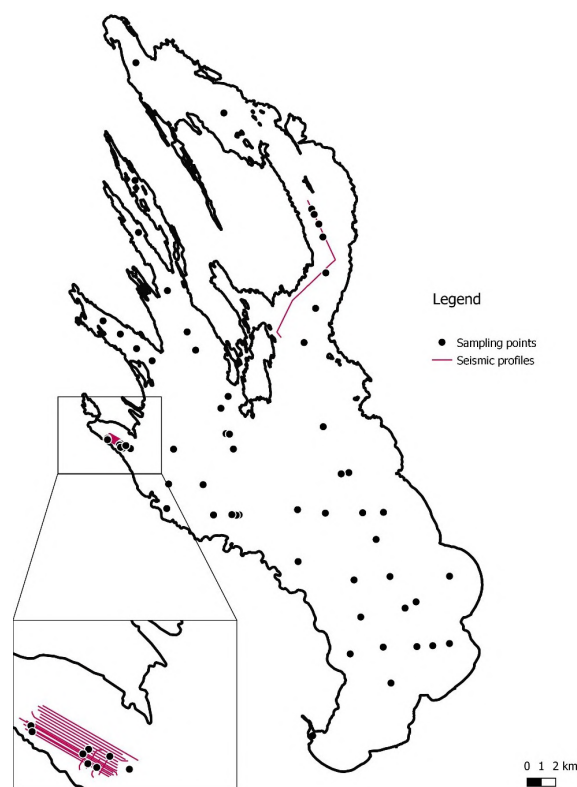


Fig.1. Map of fact material. Sampling points and seismic profiles.

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3. Results

There were the following types of deposits at the bottom of Lake Onego:

1. Moraines (gIIIos) laying at a depth of 4.85-5.44 meters blf. It consisted of gray-brown stiff loam with interlayers of sandy loam, inclusions of reddish sand and an admixture of pebbles. Towards the bottom, the density and the proportion of the sand-pebble fraction increased.
2. Fluvioglacial (fIIIos) forming eskers and accumulative fields, in some places they covered moraines (gIIIos). Consisted of brown-gray clayey sands, pebbles, sandy-clayey-silt miktites and gruss. Content of clay at the upper part could be the cause of reprecipitation of this deposits at the preglacial lake conditions.
3. Limnoglacial deposits (lgIIIos). Separates at three members (lgIII₁os, lgIII₂os, lgIII₃os), which correspond to three stages of preglacial lake conditions. The lower member (lgIII₁os) consists of rhythmic brown highly plastic clays, gray sands and sandy-clayey-silty mictites, there can be sandy bands up to 6 mm thick in this member. The middle member (lgIII₂os) consists of dark-gray sandy silts soft-hard plastic ribbon clays of gray-brown and brownish-gray color. At the upper part, visible influence of etching. The upper member (lgIII₃os) consists of gray, light brown, brown-gray microlayered clays, which turn into homogeneous fluid-plastic clays. It has sand linses, autigenic minerals (Strakhovenko et al., 2020) and pink clays, which are known as "pink horizon" (Demidov et al., 2004).
4. Modern lacustrine sediments (lnH) consisting of gray and greenish-gray fluid-plastic clayey silts and aleuopelites (lower part). The upper part is composed of greenish-gray gyttja and dark brown liquid clayey silt. Interlayers of sand, organic matter and authigenic minerals (Strakhovenko et al., 2020) are observed.

Also, at the bottom of Lake Onego pre-Quaternary bedrock exposures and undalluvium (lvIII-H) have been observed at the coastal part. Figure 2 shows the map of Quaternary sediments of Lake Onego.

After analysis of data regarding Quaternary deposits and subbottom relief of Lake Onego, it became possible to describe geomorphological features of the lake. At the bottom of Lake Onego, six types of surfaces have been observed (Beliaev et al., 2020). Here is the description of these types:

1. Intensively dissected ridge and fiardo-skerry plains on a crystalline substrate with the modern geodynamic processes. Developed at the northern part of the lake, have highly dissection, many south-eastern oriented ridges and little basins of sedimentation.
2. Ridge-wavy plains on the prepared crystalline substrate with glacial accumulative elevations. Developed at northern, north-western and southern parts of the lake, near the coast. Middle-dissected, have ridges of glacial genesis.

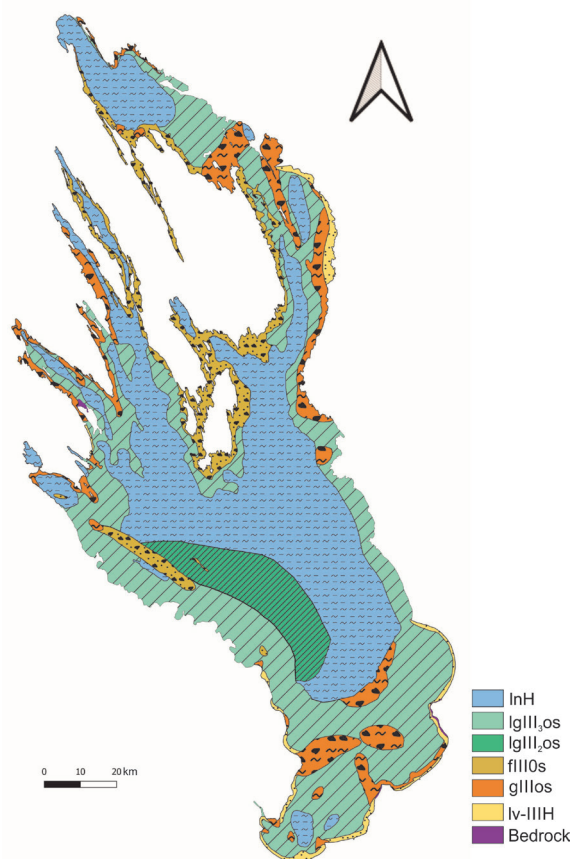


Fig.2. Map of Quaternary sediments of Lake Onego.

3. Hilly-ridged glacial and glacier-lacustrine plains on a moraine substrate (zones of marginal formations). Available in the northern, northeastern coastal and southern parts of the lake. Middle-dissected, with glacial and fluvioglacial ridges, height up to 20 meters.
4. Flattened lacustrine nepheloid plains. They occupy the middle part of the lake, and deepest parts of the bays. Characterized by the lowest dissection of surface and the maximum thickness of lacustrine deposits.
5. Subhorizontal flattened glacier-lake plains. Developed at the central and southern parts of the lake. Depths - from 10 to 70 meters. The relief is poorly dissected. At their core, they are accumulative fields formed by accumulation, characteristic of glacial reservoirs. Terraced surfaces are observed in the coastal part.
6. Undaluvial, slightly sloping plains. They were identified in the coastal zone of the South Onego Bay and in the east of the Zaonezhsky Bay. Depths less than 10 meters, there is a slope towards the deep part of the lake. Their genesis corresponds to hydrodynamic (wave) activity.

All of the types of underwater surfaces are depicted at geomorphological map (Fig. 3).

4. Discussion

Comparison of Ladoga and Onego lakes.

Quaternary sediments of Lake Onego represent glacio-sedimentary cycle with the following sediments: moraines-fluvioglacial-limnoglacial-lacustrine sediments. Each type of the sediments corresponds to stage of development of the lake during Neopleistocene and Holocene. The same sequence of sediments we have in Lake Ladoga.

If we talk about geomorphological features, we have to say, that at the bottom of Lake Onego there were observed only six types of surface, but at the bottom of Ladoga – nine types. In general, underwater surfaces of Ladoga and Onego lakes are more dissected at the northern part, and less dissected in southern. But surface of the Lake Ladoga bottom is less isometric in terms of longitudinal profile. In Lake Ladoga, deeper part is the north of the lake, but in case of Lake Onego, central part is deeper. The biggest thickness of Quaternary deposits for Lake Ladoga is typical in the northern part, and for Onego, in the northern, also in the central part. However, in both lakes, the smallest thickness of lake deposits is typical for the southern part.

5. Conclusions

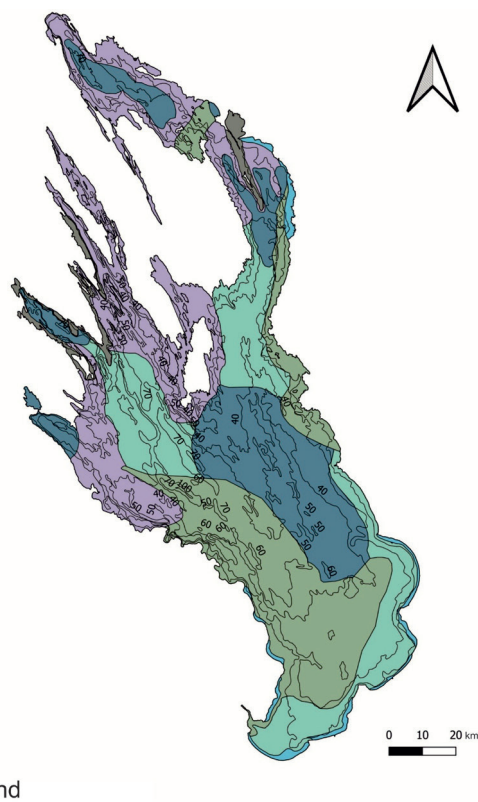
Ladoga and Onego lakes have common features in Quaternary sediments and its distribution at the subbottom surface. The differences are in geomorphological features, which corresponds to some paleogeography development conditions and structure of crystalline basement. In addition, modern hydrodynamic features influence sedimentation processes and distribution of the sediments.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.



Legend

1 2 3 4 5 6

Fig.3. Geomorphological map of Lake Onego.

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Sedimentary processes in Lake Onego at the present time

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ABSTRACT. The data on studies of sedimentation processes in the Lake Onego were collected. The research program includes monitoring of atmospheric precipitation, the river flow, the distribution of suspended matter in the water column, the flow of suspended matter to the bottom and point source of pollution. The distribution and accumulation rates of sedimentary matter in the lake were determined. The composition of sedimentary matter has been studied.

Keywords: big lake, genesis of sediments, distribution of suspended matter, geochemical composition of sedimentary matter, accumulation rate

1. Introduction

Lake Onego is the second largest Europe Lake. The catchment area (53,100 km²) and lake depression (9,720 km²) are located in the Northwest of the East European Platform on the border of the crystalline shield and the sedimentary plate (61°42' N, 35°25' E; 33 m a.s.l.). The northern part of the basin is composed of hard-to-dissolve crystalline rocks of the Archean-Proterozoic Fennoscandian shield, overlain by Quaternary deposits of small thickness (7-10 m). The southern part composed of rocks of the Upper Devonian and Lower Carboniferous. The crystalline rocks of the catchment area of Lake Onego are covered by a cover of Quaternary sediments (interglacial, continental, and marine formations of the Early, Middle, and Late Pleistocene).

Lake Onego basin has a well-developed hydrographic network including more than 6500 rivers and 9500 lakes (the lake-surface area density of 6.5%) (Litvinenko and Karpechko, 2015). The intensive destruction of Quaternary sediments is observed under the influence of denudation processes in a humid climate (Demidov, 2010; Subetto et al., 2020; Strakhovenko et al., 2018; 2020; Kulik et al., 2020a; 2020b; 2022; Belkina et al., 2008; Belkina and Kulik, 2018).

2. Materials and methods

Studies of sedimentation processes in Lake Onego include: (1) monitoring of atmospheric precipitation; (2) monitoring of river flow (10 large rivers, 4 seasons); (3) periodic observations of the distribution of suspended matter in the water column; (4) monitoring of the flow of suspended matter to the bottom (26 sedimentation traps (ST) are installed in different areas of the lake, the time exposition – 1 year (Fig.); (5) monitoring of the flow of solid material from point anthropogenic sources (official information). In order to perform task (4), a ST was constructed, a unique scheme for setting and lifting ST was developed, a method for sample preparation of suspensions from ST was developed, a method for selecting and separating suspended matter from natural water was modified.

3. Results and discussion

The features of the distribution of suspended matter in the water column are established. Increased turbidity values are typical for shallow coastal areas of bays and at the confluence of rivers into the lake. Increased turbidity values throughout the water column were recorded in shallow small bays (Kizhi

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Skerries). In deeper bays (Gorskaya and Lizhetskaya Bays), turbidity increases with depth. Pronounced heterogeneity of turbidity distribution along the water column was revealed in the Kondopoga Bay. The reason for this is the spread of polluted waters of the Kondopoga Pulp and Paper Mill. In Petrozavodskay, Unitskaya and Povenetsky Bay, the connection of seasonal and interannual changes in turbidity to the development of phytoplankton was revealed. The deep-water central areas of the lake are characterized by maximum transparency, turbidity values increase with depth. In the southern part of Lake Onego, the interannual variability of turbidity is associated with wind effects on shallow water areas and river runoff.

Monitoring of the intake of the substance into the ST showed the uniformity of the granulometric composition and the uneven nature of the accumulation of sedimentary matter in Lake Onego. The amount of solid matter entering sedimentation traps during observations varied from 0.5 to 20 g year⁻¹. Very high quantitative indicators of the average annual intake of substances to the bottom were recorded in the peripheral areas of the open part of the lake (1600 g·m⁻²·year⁻¹ in the North and 1100 g·m⁻²·year⁻¹ in the South). In the Central part of the lake, it did not exceed 590 g·m⁻²·year⁻¹. The maximum average annual intake of the substance in the bottom was recorded in the upper part of the Kondopoga Bay (more than 2 kg), but on average in the bay it was 1100 g·m⁻²·year⁻¹ (the range of fluctuations in values in this bay is the widest). The minimum values of the average annual intake of substances to the bottom were recorded in the Povenetsky Bay (350 g·m⁻²·year⁻¹, with fluctuations of 140 – 500 g·m⁻²·year⁻¹) and at the outlet of the Gorskaya Bay (270 g·m⁻²·year⁻¹, fluctuations of 160-370 g·m⁻²·year⁻¹).

The rate of accumulation of suspended matter at the bottom, expressed in units of length (the thickness of the accumulated layer per year), varies by more than an order of magnitude for different stations: from 1 mm·year⁻¹ (C4) to 3 mm·year⁻¹ (K3) (on average 7 mm) of freshly deposited unconsolidated matter. Differences in the depths of the lake, as well as in the qualitative and quantitative composition of sedimentation material and differences in diagenetic transformations determine the different degree of compaction of the substance entering the bottom during the formation of bottom sediments. The lowest sedimentation rates were estimated for the deep-water areas of the lake: Bolshoe Onego, Povenetsky Bay and Lizhetskaya Bay. The highest rate of sedimentation is observed in the shallow upper part of the Kondopoga Bay, where bottom sediments are formed under the influence of wastewater from the Kondopoga Pulp and Paper Mill. The obtained values of the sedimentation rate for two stations (L18 and S3) were compared with the values of the sedimentation rate based on age dating by the distribution of isotopes ¹³⁷Cs and ²¹⁰Pb in the sediment column. The values were close: for L18 – 0.23 and 0.16 mm·year⁻¹, for the southern part of the lake (S3) – 0.43 and 0.47 mm·year⁻¹, respectively.

Chemical composition of the waters and the

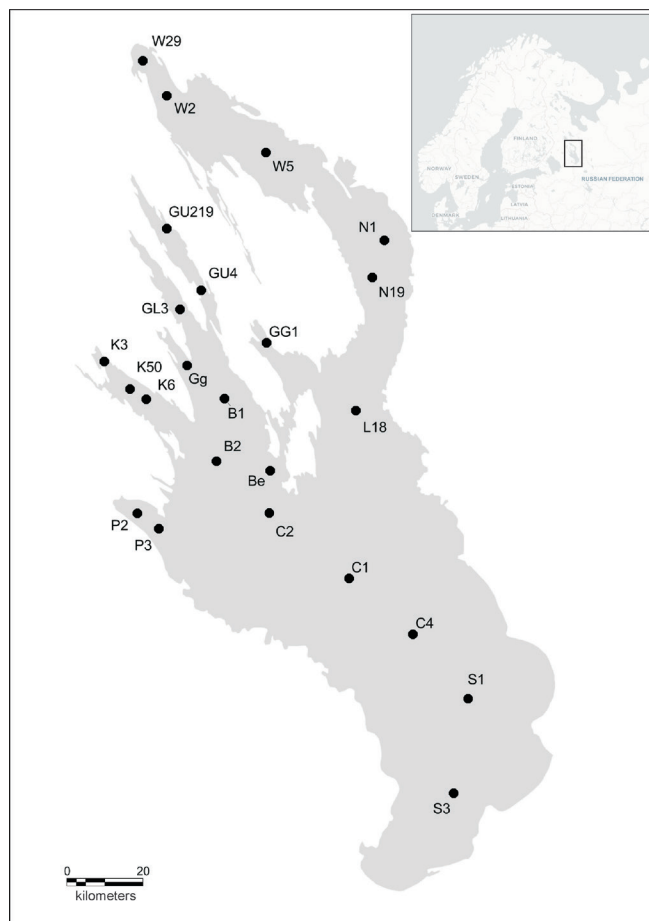


Fig. Monitoring stations for studies sedimentation processes in Lake Onego

elemental, mineral and detrital particle composition of sedimentary matter in rivers and lake have been studied. The ratio of suspended and dissolved forms of elements varies depending on the area of the lake (the suspended form predominates mainly in Petrozavodsk and Kondopoga bay). The detrital matter in Lake Onego is represented by skeletons of diatoms, which are destroyed as they are deposited. The terrigenous component from ST and bottom sediments collected in different parts of the lake have a similar composition. It is represented by fragments of large and small grains of quartz, feldspar, muscovite, chlorite (which contain the ratio Fe ≈ Mg) and numerous small grains of accessory minerals. The suspended material of the sedimentation traps is similar in its external characteristics and physical properties to the surface (0-1 cm) bottom sediment in the areas of their installation on the lake bottom.

4. Conclusions

The basin of the Lake Onego has a complex structure, which affects the thermal regime and the dynamics of the waters, increases the heterogeneity of the ecosystem of the lake. As a result, there are local sedimentation basins with their own regime in the lake.

The sedimentary process in Lake Onego, controlled by water dynamics, involves the transformation of suspended matter in a complex

biogeochemical way, resulting in the formation of new mineral phases of iron, manganese and silicon.

The rate of accumulation of suspended matter at the bottom varies by more than an order of magnitude for different areas of the lake.

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Conflict of interest

The authors declare no conflict of interest.

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Evolution of vegetation in the Utinoe Lake basin (the Russian Far East) during the Middle-Late Holocene

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ABSTRACT. Evolution of vegetation in the Utinoe Lake basin was studied. Periodicity of vegetation changes in its basin were reconstructed by the palynological data. The Middle Holocene stage of the vegetation evolution proceeded in the conditions of general planetary increase in average annual temperatures, accompanied by flooding of lowland plains by the Sea of Japan. Composition of the polydominant forests on the ridges during the Middle-Late Holocene was more rich what the present time were formed. Vegetation of the foothill plains was represented with sedge and mixed meadows. The Late Holocene stage was characterized by a decrease in average annual temperatures and series of climatic changes. Its beginning was marked by the cooling, during which the coastal lowlands were freed from sea waters. Climate deterioration caused expansion of dark coniferous and small-leaved plants in the Utinoe Lake basin, as well as reduction of polydominant forests. On the foothills near the coast of the Peter the Great Bay sedge meadows were developed, sometimes there were thickets of *Betula* sect. *Nanae* and sphagnum swamps. At the end of the Late Holocene the warming occurred again. On the mountain frame of the Utinoe Lake basin, the vegetation formations with the dominance *Q. mongolica*, *Q. dentata*, *A. holophylla*, *P. koraiensis* with the presence of birches began to dominate. The dissemination of *Pinus densiflora*, *Ulmus*, *Carpinus cordata* and *Acer* has increased. On the lowlands the sedge-reed meadows with different grass dominated.

Keywords: vegetation changes, Late Holocene, mid-Holocene Thermal Maximum, Utinoe Lake, pollen assemblages

1. Introduction

Climatic changes during the Holocene was a trigger for global plant migrations. Its were most noticeable in the contact zone of floristic provinces. The south of the Russian Far East is such area. This region is located in the contact zone of the Amur, Manchurian and North China floristic provinces of boreal and warm-moderate belts (Komarov, 1901). Therefore, this is a key area for the studies on plants migrations due to climate fluctuations. This paper presents the results of an analysis of the evolution of vegetation in the basin of Lake Utinoe during the Middle -Late Holocene.

2. Materials and methods

2.1. Collection and preparation of the sediment samples

Drilling of boreholes on Lake Utinoe was carried out from a floating platform on a catamaran using a piston sampler of the Livingston system. The core was

extracted in sections that were 1m long and 5cm in diameter. In the case of high sediment density, short core sections were extracted. Samples were taken every 5-10 cm.

2.2. Palynological analysis

Fossil pollen particles were extracted from the sediments using standard methods, which included treatment with 10% KOH, separation of minerals with a solution of KJ and CdJ₂ (2.2 g/cm³), after which the samples mounted in glycerol jelly (Pokrovskaya, 1950).

Pollen and spores in glycerin jelly were identified, photographed and counted using an optical microscope Axio Scope.A1 and camera AxioCam ICc1 (Carl Zeiss). At least 250 pollen grains of arboreal, dwarf shrubs, and herb were counted in each sample. Identifications of pollen grains were made with the aid of pollen atlases (Pokrovskaya, 1950; Nakamura, 1980).

Proportion of each pollen taxon was calculated in percent of the pollen sum arboreal taxa, dwarf shrubs

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and herbs. Latin names are given according to Plants of the World Online (POWO, 2019). The results of the palynological analysis are plotted in diagrams using the software Tilia v. 2.0-41 (Grimm, 2004).

2.3. Dating

The chronology of the pollen records was based on radiocarbon dates. Five samples of wood and plant detritus, were dated by AMS ^{14}C in the Laurence Livermore Center for Accelerator Mass Spectrometry, National Laboratory, Department of Energy, University of California (Anderson et al., 2017) (Table).

3. Results and discussion

The pollen assemblage from a depth interval of 6.2–2.2 m indicates that polydominant forests with the *Quercus*, *Tilia*, *Carpinus cordata* and *Betula schmidtii* were widespread in the basin during the Mid-Holocene Thermal Maximum. Apparently, the *Quercus* was represented by two species, *Quercus mongolica* and *Q. dentata*. At the same time, the distribution of *Pinus koraiensis* in plant formations noticeably decreased, however, *P. densiflora* appeared due to an increase in the dryness condition. Similar materials were previously received by Mikishin and Gvozdeva (2014) and Pavlyutkin and Belyanina (2002).

As a result of the shifts of boundaries of floristic provinces to the north, more species from the North China Floristic Province grew in the basin compare to the present. The five-pore pollen grains of *Carpinus* were found in the sediments of the Mid-Holocene Thermal Maximum. It likely indicates that, in addition to *Carpinus cordata*, another species from the same genus was also distributed in basin. It should note that now south of 40 ° N in the Korea and Northeastern China, *Carpinus* is presented by 7 species, and *Quercus* and *Pinus* by 9 species each (Komarov, 1901).

Late Holocene stage of vegetation was accompanied a decrease in mean annual temperatures. Vegetation changes were undulating due to the climate fluctuations. The beginning of this stage is fixed by a slight decrease in content of broad-leaved species in the depth interval of 4.13–2.2 m (see Fig. 1). Global cooling

was a cause to expansion of dark coniferous and small-leaved plants. Shrub birch appeared on the plains and sphagnum mires arose. However, a short-term warming also took place in the middle part of the Late Holocene. It is marked by an increase in the pollen of *Quercus*, *Ulmus*, *Pinus koraiensis*, *Juglans mandshurica*, *Carpinus* and *Abies holophylla* compared to the depth interval of 6.2–2.2 m. Sedge-forb-reed grass meadows were widespread in the plains.

A slight increase in pollen from small-leaved plants and a decrease in the amount of broad-leaved species up the borehole, reflecting another cooling.

Another short-term warming, related to the Medieval climatic anomaly (Wanner et al., 2008), is recorded in the depth interval of 2.2–0 m. The broad-leaved taxa, especially *C. cordata*, increases in the pollen assemblages (up to 8%).

4. Conclusions

The obtained palynological data made possible to reconstruct the evolution of vegetation in the Utinoe Lake basin in the Middle- Late Holocene. A wide distribution of polydominant forests with *P. densiflora* and *P. koraiensis* in the mountainous surroundings of Lake Utinoe occurred at the mid-Holocene Thermal Maximum. Apparently, they included plants whose modern ranges cover the north of the Island Honshu and south of the Island Hokkaido (Jisaburo, 1965), Korean Peninsula south of 40°N (Lee, 1980) and the eastern regions of Manchuria. Some genera were represented by a richer species diversity. At the end of the Middle Holocene and in the first stage of the Late Holocene, due to cooling, the distribution of broad-leaved plants – *Phellodendron*, *Tilia*, *Carpinus*, *Acanthopanax*, *Juglans* and others decreased. The areas of small-leaved forests with *Picea*, *P. koraiensis*, *Alnus*, *Duschekia* and *Betula* have expanded. Shrub birch appeared on the plains, and sphagnum mires appeared. The short warming in the middle of the late Holocene led to the dominance of plant formations with *P. densiflora*, *P. koraiensis*, *Q. mongolica*, *Abies* and *Betula*. However, the slight cooling that followed then caused the expansion of small-leaved plants. Mixed forests with *P. densiflora*, *P. koraiensis* and *Abies* were formed.

Table. Radiocarbon and calibrated ages, from the bottom sediments of the Utinoe Lake (Anderson et al., 2017)

Depth, m	Material dated	Laboratory number	Date (^{14}C BP)	Calibrated age range, cal. BP
4.71-4.68	wood	CAMS # 73295	5000 ± 80	5763 ± 98
3.47-3.45		CAMS# 76800	3920 ± 40	4356 ± 59
2.46-2.45	plant detritus	CAMS # 75544	3890 ± 40	4329 ± 64
2.23-2.21		CAMS # 76799	2510 ± 60	2589 ± 109
1.30-1.27	wood	CAMS # 76798	1810 ± 60	1736 ± 80

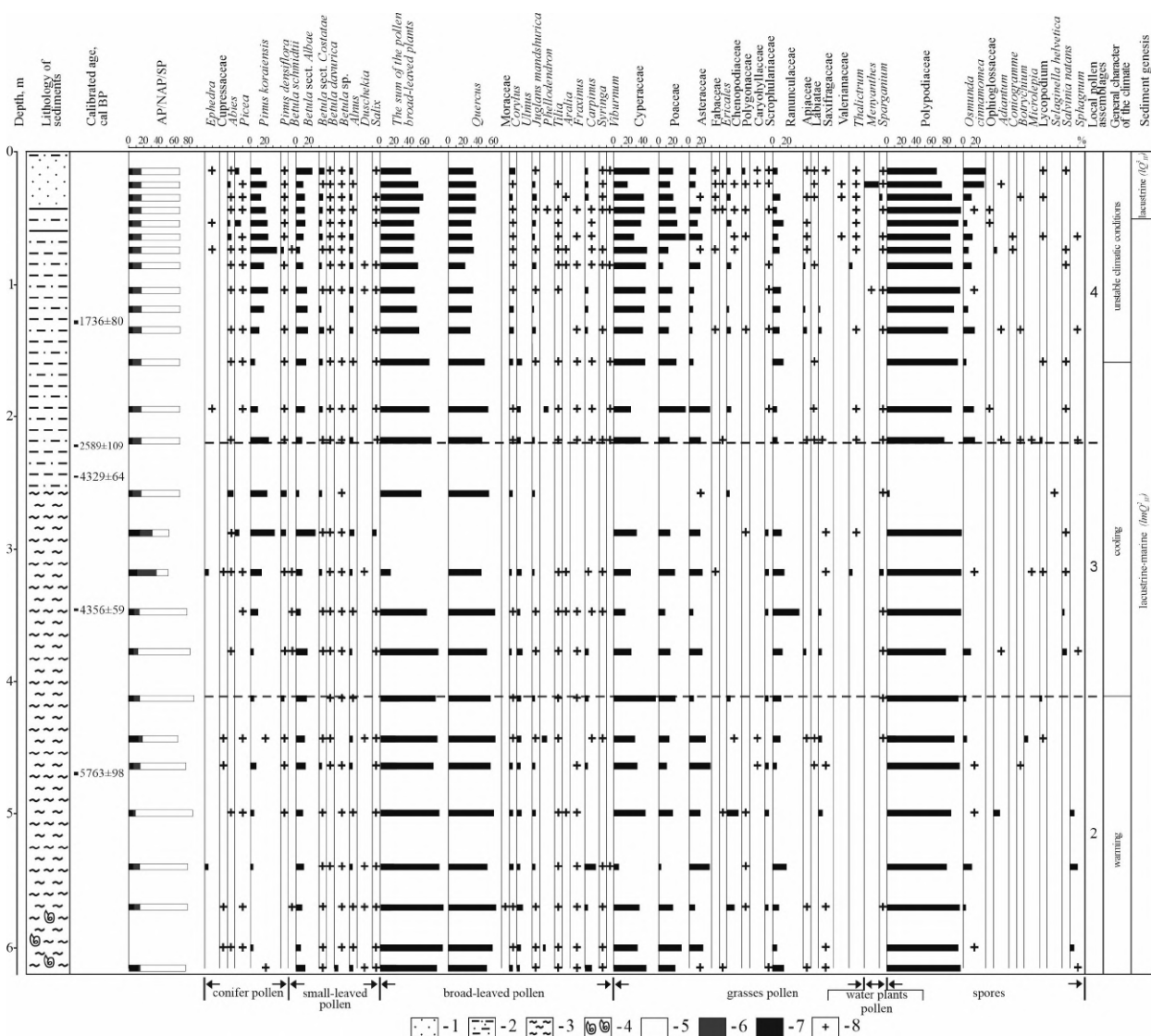


Fig.1. Pollen percentage diagram of Utinoe Lake bottom sediments. 1 – sand, 2 – sandy loam, 3 – silt, 4 – sea mollusk shells. The relationships between plant groups: 5 – AP, 6 – NAP, 7 – SP, 8 – the taxa are present in the assemblage in amounts less than 3%.

Conflict of interest

The authors declare no conflict of interest.

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Approaching a new theory on Caspian Sea response to global climate changes during MIS2 - MIS1: generalization and reassessment of $\delta^{18}\text{O}$ data

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ABSTRACT. The study represents correlation $\delta^{18}\text{O}$ records from the Caspian basin together with available stable oxygen data on the continual sequence of deep-sea cores and on Kara-Bogaz-Gol Gulf, nearby lakes, and caves to complete palaeogeographical reconstruction of the Caspian Sea region. Typical Quaternary caspian ostracods shells and valves were measured for the $\delta^{18}\text{O}$ analysis. Oxygen isotope data allowed to correlate region transgressive-regressive events with glacial-interglacial rhythm and global climate changes. It was distinguished three main evolution stages of the Caspian Sea region, including the Last Ice Sheet degradation with a series of step-like environmental shifts matching the sequence of abrupt cooling/warming events; abrupt warming at the beginning of the Holocene; and climatic fluctuations of a smaller scale and different sets during the second part of the Holocene. It was established that Caspian Sea level oscillations occur as a response to climatic changes among numerous probable causes. Transgressions were usually accompanied by the freshening of water and cold climate while regressions were primarily correspond to increased salinities and warm climate. The reconstruction of the Caspian Sea hydro-climatic changes was confirmed by observed similar trends in the oxygen isotope record of nearby regions.

Keywords: stable oxygen isotopes, Pleistocene-Holocene transition, sea level changes, correlation

1. Introduction

The Caspian Sea (CS) is highly variable on spatial and temporal scales, fluctuating substantially in the geological and historical past. After more than a century of research, there is not yet a full understanding of the amount and causes of the sea-level fluctuations and the dynamics of the Sea. Instrumental observations for the CS level (CSL) and hydrometeorological parameters cover only the last 150 years. The rare studies available so far on the CSL during the Late Pleistocene and Holocene have been made inferred from coastal sections or in the shallow northern basin and suffer from deposition hiatuses during low-stand periods and sedimentation starvation. Closed basins or lake systems in general and the Caspian Sea, in particular, are important paleoclimate archives that preserve paleogeographic and hydrologic responses to critical periods in Quaternary history, such as glacial-interglacial cycles.

Measurements of $\delta^{18}\text{O}$ biogenic carbonate are indicators of paleogeographic variability in such systems throughout the geologic record. The correlation of paleogeographic events within the region

is as important as a comprehensive consideration of the history of the development of the CS against the background of global climate changes.

Here we use our $\delta^{18}\text{O}$ records from the Caspian basin together with available stable oxygen data on the continual sequence of deep-sea cores and on Kara-Bogaz-Gol Gulf, The Black Sea, nearby lakes, and caves to complete palaeogeographical reconstruction of the CS.

2. Materials and methods

The use of the stable oxygen isotopes in combination with the micropaleontological studies appears to be a most productive way to study the regional natural processes which are developed during considerable time intervals. We study three marine cores from the Central and 4 cores from the Southern parts of the CS. The applicability of ostracods, which are more common in the cores compare to foraminifera, for stable oxygen isotope analysis was proved during the last century. We measured $\delta^{18}\text{O}$ in typical Quaternary Caspian ostracods shells and valves.

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Samples were sieved through a 63 µm mesh using distilled water. The dry fractions 0.1–2 mm and 0.063–0.1 mm were analyzed using a binocular microscope. After full ostracod record and taxonomic revision for integration with ecological data ostracod samples were picked for stable oxygen measurements. The analyzes were performed at the Center for Collective Use, Primorsky Center for Local Elemental and Isotopic Analysis of the Far Eastern Geological Institute, Far Eastern Branch of the Russian Academy of Sciences, Vladivostok using The Finnigan MAT 253 stable isotope ratio mass spectrometer system.

3. Results and discussion

We correlate the results with our previous data on stable oxygen composition of the North Caspian cores (Berdnikova et al., 2018), four deep-sea cores from the joint Russian-French expedition, organized in 1984 (Ferronsky and Polyakov, 2012), core from the north-west part of the Kara-Bogaz-Gol Gulf (Ferronsky and Polyakov, 2012), Eski Acigol former crater lake in the Central Anatolian volcanic province (Roberts et al., 2001), Van Lake (Wick et al., 2003; McCormack et al., 2019), Zeribar Lake (Stevens et al., 2001), Mirabad Lake (Stevens et al., 2006), Karakul Lake (Aichner et al., 2019) and Issyk-Kul Lake (Ricketts et al., 2001), Sofular cave (Fleitmann et al., 2009), Poleva Cave (Constantin et al., 2007) and Katalekhora cave (Andrews et al., 2020).

Oxygen isotope data allow us to correlate the transgressive-regressive events in the region with glacial-interglacial rhythm and global climate changes.

We distinguish several evolution stages for the region:

1. The Last Ice Sheet degradation. A series of step-like environmental shifts may match the sequence of abrupt cooling/warming events recorded in different paleo-archives (like the Greenland ice cores).
 - 1.1 Values of $\delta^{18}\text{O}$ were higher for 19-16 ka. A similar trend was observed in data from the nearby lakes. For such periods with the light in isotopic compositions were characterized by an high sedimentation rates.
 - 1.2 Complex internal dynamics: two distinct peaks in the higher isotope composition during Bølling-Allerød warming and the lower $\delta^{18}\text{O}$ values during the stadials (change to glacial conditions at the onset of the Younger Dryas). CSL change was presumably a result of shifts in temperature and precipitation. The isotopic characteristics were changed in a different manner along for the southern and middle sections of CS.
2. Abrupt warming at the beginning of the Holocene. An abrupt increase of isotope ratio likely illuminated significant shifts in lake-water balance.
3. The climatic changes of the second part of the Holocene reflected differently in various cores: staggered weighting/stabilization and increase of isotope values.

4. Conclusions

According to our results, CSL oscillations occur as a response to climatic changes among numerous probable causes. Transgressions are usually accompanied by the freshening of water and cold climate while regressions primarily correspond to increased salinities and warm climate. Within the considered paleo-geographical period the upcoming transition was accompanied by a plentiful glacier and permafrost melting, and by increased river runoff, CSL changes as a result of shifts in both temperature and precipitation, and finally abrupt warming. The reconstruction of the CS hydro-climatic changes was confirmed by similar trends observed in the oxygen isotope record of nearby regions.

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Conflict of interest

The authors declare no conflict of interest.

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Late Glacial and Holocene environmental history of the Oka Plateau, East Sayan Mountains (Siberia): a palaeolimnological study of several lakes

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ABSTRACT. Palaeoenvironmental changes including vegetation, chemical weathering intensity, lake's water level fluctuations, and climate dynamics in the East Sayan Mountains were investigated using pollen, mineralogical, petromagnetic, X-ray fluorescence analyses and radiocarbon dating. Based on these data sets from three high-mountain lakes, we reconstructed the variations in local and regional vegetation, biomes, and climate during the Late Glacial and Holocene in the Oka Plateau, East Sayan Mountains, and the surrounding areas.

Keywords: vegetation and chemical weathering history, climate, Late Glacial-Holocene, Oka Plateau, Siberia

1. Introduction

Climate and natural ecosystems change has become unusually pronounced in recent decades, impacting the environment and vegetation in Siberia and in the Russian part of the Altai-Sayan region. The current climate warming observed in southern Siberia is most evident in the alpine belts and ecotone zone between alpine and forest belts of the Altai and Sayan Mountains (Kharlamova et al., 2019) and is leading to aridification of the mountain steppes, altitudinal tree-line migration and restructuring of mountain biotopes. To understand the nature and possible causes of variations in recent ecosystems, it is necessary to assess the long-term patterns of their development. Mountain lake sediments provide continuous, high- to relatively high resolution sequences that embody a richness of physical, chemical and biological “proxies”, tracers that can be used to infer paleoclimate, -hydrology, -soils and -vegetation. The main goal of our study is to reveal the long-term evolution of the natural environment on the Oka plateau in the Late Glacial-Holocene time.

2. Materials and methods

Sediment cores from glacial lakes Kaskadnoe-1, Khikushka and Khara-Nur were recovered using a rope-operated UWITEC Piston Corer with PVC liners.

Seventeen AMS¹⁴C ages were obtained at different laboratories (Poznan and Moscow). Radiocarbon ages were then calibrated using R package version 2.3.9.1. (Blaauw and Christen, 2019) and the IntCal20 calibration curve (Heaton et al., 2020). Magnetic susceptibility (MS), biogenic silica SiO_{2bio}, dry bulk density (DBD) were measured at 1 cm intervals. A standard procedure was used to extract pollen (Berglund and Ralska-Jasiewiczowa, 1986). The potential of the biome reconstruction (‘biomization’) method (Prentice et al., 1996) was used for the quantitative interpretation of the pollen spectra.

3. Results and discussion

The obtained dates suggested accumulation of the recovered core sediment during the Late Glacial and Holocene. According to the age-depth relationship, the lower part of the silty clay in the Kaskadnoe-1 and Khikushka cores were accumulated ~ 13.3–10.1 ka BP (calibrated thousands years before present) and ~ 13.5–10.5 ka BP, respectively. Since then, biogenic terrigenous silt enriched with diatoms has formed. The sediments in the Khara-Nur lake core are represented by biogenic terrigenous silts, underlined by thin layers of peat-peaty sands.

The pollen records indicates a considerable development of shrub and herb tundra around

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Kaskadnoe-1 and Khikushka lakes ca. 13.4-12.1 ka BP during cold climate. But rather high abundances of spruce *Picea* and larch *Larix* pollen indicate their presence around the lakes suggesting rather humid local environments (Fig.). Maxima in MS and DBD values in the records indicate a significant contribution of terrigenous material from the catchment area, probably carried by water originating from melting glaciers. *Abies* pollen rise since 12.1 ka BP points out to fir arrival close to Kaskadnoe-1 and Khikushka lakes under more favorable than earlier climate that lasted until ca. 8.0 ka BP (Fig.) being in line with predominantly warm and humid Early Holocene across western Mongolia and Altai and Baikal Regions (Klinge and Sauer, 2019). Warming favors the regional rather than local rise in the upper elevational limits of *Pinus sibirica* and the steady increase in *Pinus sylvestris* across the region since ca. 11.2 ka BP. An expansion of pines at higher elevations shortly after local deglaciation in the study area as opposed to their significantly later spread (7500-6000 ka BP) on plains of south East Siberia (Kobe et al., 2020) could be related to early spring melting and a longer growing season due to higher summer insolation. Although, other data support a predominantly treeless landscape in the lake basins ca. 8.0-4.5(4.0) ka BP. A strong reduction in dark coniferous fir and spruce trees in the middle Holocene in the lake basins could be a result of the higher-than-present summer insolation that could lead to warm summers, high evaporation and moisture deficit for dark coniferous trees.

A reconstructed spread of *Larix* after 4.5 ka BP in the vicinity of all three lakes and approach of *Pinus sibirica*, are in parallel to a decrease in summer insolation and an increase in winter insolation, which in turn, led to weakening in the activity of both summer monsoon and winter anticyclone. Moreover, the westerlies, bringing rain and snow precipitation to the middle latitudes of Eurasia, Altai Mountains (Rudaya

et al., 2009) and Baikal Region (Kostrova et al., 2020) became stronger.

4. Conclusions

Based on pollen data from three high-mountains lakes, we reconstructed the variations in local and regional vegetation, biomes, and climate during the Late Glacial and Holocene in the Oka Plateau, East Sayan Mountains, and the surrounding areas. Our data revealed new insights into the Late Quaternary climate and environmental history of this region.

Predominantly open steppe- and tundra-like vegetation dominated the area during the Late Glacial, with noticeable participation of boreal trees. A short-term reduction of the forest biome at ca. 12600-12500 cal. yr BP could be a response of regional vegetation to climate deterioration during the YD stadial. Climate warming and decrease in effective moisture after 11.2 ka BP led to the degradation of dark coniferous forests in the study area and to a gradual expansion of *Pinus sylvestris* and *Pinus sibirica*. Warmest climate existed during the Early-Middle Holocene. The *Larix* stands may have re-established in the study region soon after 4.5 ka BP. This trend is in parallel to a decrease in summer insolation and an increase of winter insolation. Our new results provide additional evidence for sensitive responses of various boreal lacustrine ecosystems to global climatic changes in the Late Glacial-Holocene.

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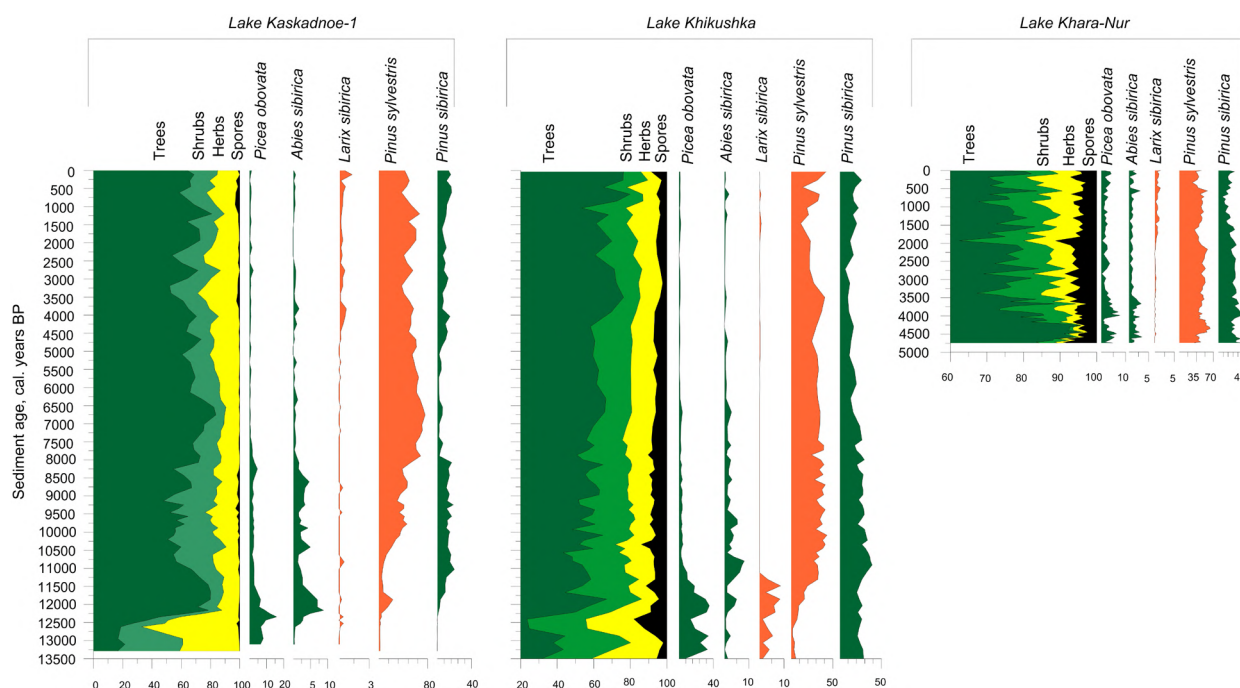


Fig. Variations in the total composition of pollen and spores in the sediments of the lakes studied as an indicator of the regional vegetation progress, and arboreal taxa pollen as an indicator of local/regional vegetation

Conflict of interest

The authors declare no conflict of interest.

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Long-chain alkenones in the lake sediments of North-Minusinsk Basin (South Siberia): implications for paleoclimate reconstructions

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ABSTRACT. The core-top calibration study of 22 lakes indicates that in salt lakes the total alkenones increase sharply at a salinity of about 20 g/L, while alkenones are absent in the sediments of freshwater lakes. For the first time, this study shows that the Uk40 and Uk40' unsaturation indices are positively correlated with salinity and thus can be used to reconstruct salinity. The C37/C38 ratio is negatively correlated with salinity, and therefore this parameter can be used as an indicator of salinity. Also, the %C37:4 indicator is not correlated with salinity. It was found that the average chain length of alkenones increases with salinity, but the correlation was weak. Analysis of the alkenone composition and 18S rRNA suggests that all lakes are inhabited by Group II haptophytes, except for one freshwater lake, where the Group I of LCA-producing haptophytes was found. The taxonomic composition of haptophyte algae and the alkenone composition in the lakes were comparable to those in the lakes of the Canadian Prairies, apparently due to the similarity of climatic factors and the ionic composition of lake water in the two regions.

Keywords: alkenones, salinity indicator, lake sediments, South Siberia, paleoclimatology

1. Introduction

Knowing how the climate has changed over the past 2000 years is essential to understanding the relationship between current global warming and natural climate fluctuations. (McKay and Kaufman, 2014). Nevertheless, the patterns of climate fluctuations in the higher latitudes of Asia, for example, in Siberia, have not been studied enough. The Minusinsk Hollow is one of the site of special interest for paleoclimate research. Reconstruction of the paleoclimate from lake sediments can help reveal patterns of climate variations. In regions with arid and semiarid climate, endorheic lakes are sensitive to fluctuations in the balance of precipitation and evaporation. They respond by changing the volume of water, and the change in water salinity is inversely proportional to the change in volume. Significant research efforts have recently been focused on the search for molecular markers of climatic variations, among which the most promising are long-chain alkenones (LCAs). LCAs are C35–C42 methyl and ethyl ketones with 2-4 unsaturated double bonds in the aliphatic chain (Araie et al., 2018). Based on the 18S rRNA gene analysis, all known alkenone-producing haptophytes were divided into three groups: Group I

freshwater species; Group II the species inhabiting waters of a wide range of salinity levels and Group III marine species. The C37/C38 ratio has been shown to decrease with increasing salinity. A more recent study has shown that in some lakes the proportion of %C37 relative to total alkenones is negatively correlated to salinity. It has also been observed that the average length of alkenones positively correlates with salinity. Except for a few lakes on the vast territory of Siberia, alkenones and the species composition of alkenone producers have not been studied yet.

Thus, the purpose of the current study was to analyze the relationships between the distributions of alkenones, and taxonomic composition of their producers and external factors in the region of Minusinsk Hollow where such research had not been done before and assess potential for alkenone-based regional paleo-reconstructions.

2. Materials and methods

The sediments core samples were collected from 21 lakes situated in the North-Minusinsk Valley during the field studies on July 24–26, 2019 and May 15–17,

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2020. Additionally, samples from Lake Slabitelnoye-2 were collected on July 21, 2021. Sediment samples were collected using a corer sampler UWITEC (Austria) at positions located in the central parts of the lakes. Then, the top 1-cm sediment layers were placed into separate sealed plastic bags and stored at -20 °C. Before sample collection, vertical profiles of temperature, conductivity, oxygen, pH, and redox potential were measured using a YSI EXO2 multi-parameter water quality sonde. Water samples for analysis of haptophyte DNA were collected from several lakes where alkenones were detected using a 0.5-L bathometer.

At the Analytical Laboratory of the Institute of Biophysics SB RAS, wet sediment samples (5–10 g) were dried at 50 °C until completely dry. Then alkenones were extracted for 24 h using the chloroform–methanol mixture (7:3 v/v) supplemented with the internal standard. After that, saponification was performed. Non-saponifiable components were separated using a 7890/5975C GC-MS chromatograph (Agilent Technologies, U.S.A.) with a VF-200MS capillary column. Identification of LCAs was based on determining molecular weight, the ratio of the weight to the base peak charge, and comparison of mass spectra with those available in literature (Jaraula et al., 2010).

For DNA analysis, water samples (40–300 ml each) were filtered through Advantec 0.2-µm cellulose acetate membrane filters and after that sample filters were stored at -20 °C. Total DNA was extracted using DNeasy PowerSoil Kit (Qiagen) according to the manufacturer's instructions. DNA was amplified using micro-eukaryote-specific primers V4F and V4RB containing adapter sequences (Illumina), linker, and barcode. Sequencing was performed at the SB RAS Genomics Core Facility (ICBFM SB RAS, Novosibirsk) using a MiSeq DNA sequencer (Illumina) with Reagent Kit v3 (2×300, Illumina). Phylogenetic analysis was based on the obtained operational taxonomic units (OTUs). Closest relatives were identified with the GenBank database (NCBI) using BLASTn. Multiple alignment of 18S rRNA gene sequences of all selected organisms was performed using the Muscle algorithm in MEGA X. The phylogenetic tree was constructed based on the Neighbor-Joining algorithm. Tree branch support was evaluated using the Bootstrap method with 1000 iterations.

Multivariate analysis by the RDA (redundancy analysis) method was performed in the R software environment using the vegan package. All data were previously (log+1) transformed and standardized in the same package.

3. Results and discussion

Study lakes differed substantially in their characteristics. Salinity varied between 0.02 and 44 g/L and depth between 0.9 and 44 m. Anion SO_4^{2-} prevailed in most lakes, but in some brackish lakes (with salinity of 0.5–3 g/L) and freshwater ones (salinity below 0.5 g/L), the dominant anion was HCO_3^- . The dominant cation in all lakes except Lake Fyrkal was Na^+ followed

by Mg_2^+ . In freshwater Lake Fyrkal, Mg_2^+ prevailed over Na^+ .

The total content of alkenones in the sediments varied widely, between 4 and 7400 µg/g dry sediment, with the exception of four freshwater lakes where alkenones were not found. Alkenone concentrations showed a strongly nonlinear salinity dependence: they were low in lakes with salinity up to 20 g/L, increasing dramatically, by two orders of magnitude, at salinity above 20 g/L. In the salinity range between 20 and 30 g/L, there were alkenone concentrations above 1000 µg/g dry sediment, and at salinity above 30 g/L, alkenone concentrations decreased.

C37–C39 alkenones were detected in all lakes. In the lakes with the total alkenone concentrations >100 µg/g, there were also C40 alkenones, but their proportion was the lowest in the total alkenone content. C37 and C39 alkenones were represented by methyl isomers, and C38 and C40 by ethyl isomers. Unlike other lakes, the isomers C37:3b and C38:3b were detected in Lake Matarak. The C37/C38 ratio varied between 1.11 and 3.54. A significant anti-correlation was revealed between the C37/C38 ratio and salinity (-0.5 , $n=18$, $p<0.05$). There was practically no correlation between %C37:4 and salinity. A significant correlation was found between salinity and indices Uk40 ($r=0.72$, $n=11$, $p<0.05$) and Uk40' ($r=0.86$, $n=11$, $p<0.05$).

Only 10 OTUs were identified as *Haptophyta*, and four of these were of the order *Isochrysidales*. *Isochrysidales*, which have been so far regarded as the only producers of alkenones, were detected in all alkenone-containing lakes except Lake Shunet, where they were not found. In Lake Krasnenkoye (at the village of Borets), where no alkenones were detected, no *Isochrysidales* OTUs were identified as well. Alkenone-producers of the Group II were found in all other studied lakes, except for Lake Matarak where OTU 878 showed 100% similarity of the sequences with phylotypes of Group I typical for freshwater lakes. OTU 6 from Lake Uchum showed 100% similarity with *Isochrysidales* sp. phylotype MK092737.1 from Canadian lakes; it was assigned to Group II of alkenone producers.

The RDA (redundancy analysis) method showed that Total alkenones (TotAlk) had a stronger correlation with salinity than with any other parameter. The lakes formed several distinct groups. Group I included freshwater lakes, in which there were no alkenones: Kiprino, Itkul, Fyrkal, and Krasnenkoye (close to the village of Borets). Group II comprised saline and brackish lakes containing alkenones.

4. Conclusions

For the first time, the potential of alkenones for reconstructing salinity in the semiarid steppe region in South Siberia was studied, and it was found that alkenone properties and their relationship with external factors are generally similar to those previously established for other regions. Total alkenones in sediments can increase dramatically at salinity above 20 g/L; hence, alkenone peaks in sediment cores can

indicate an increase in salinity and the exceeding of the threshold of 20 g/L caused by the drying of the closed lakes. In addition, new indices of unsaturation of C40 alkenones were used and their correlation with salinity was shown; however, the data are not sufficient to definitely them as salinity indicators. Studies have shown that the species composition of alkenone producers and the range of alkenones are similar to those in North America regions with the same climatic conditions.

Acknowledgements

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Conflict of interest

The authors declare no conflict of interest.

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Macro-charcoal particles in lake sediments of North-Minusinsk Basin (South Siberia, Russia) as indicator of natural and human-induced paleo-fires

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ABSTRACT. Microscopic analysis of the core from the bottom sediments of Lake Shira (southern Siberia, Khakassia, Russia), have shown that for the last 100 years the sedimentation flux of charcoal particles sharply increased. This increase is consistent with the results for many lakes in the world and is presumably due to the current increase in anthropogenic impact, both in the form of accidental and deliberate arson, and in the form of burning wood and coal for heating residential buildings and recreation in the area adjacent to the lake. A flux of charcoal particles >100 µm into Lake Shira was estimated base on sedimentation traps in 2012-2019. It was shown that the particle flux increasing from October to May, which can be explained by two factors: the burning of fuel from surrounding villages at cold time and fires of steppe in April-May. During the warm season, this flow are significantly decreased, therefore, a impact of campfires is likely minor compare to village sources. Our data show a significant contribution of anthropogenic factors to the flow of coal particles from burning fuel and spring fires.

Keywords: charcoal, fires, lake sediments, sedimentation traps, Lake Shira

1. Introduction

The forecast of fire regimes under various climatic scenarios is an extremely urgent for Siberia, where fires pose a serious threat to natural ecosystems and a people. For an adequate forecast, information is needed on the frequency and intensity of fires in the past. In addition, a comparative assessment of the contribution of anthropogenic factors to the modern fire situation can only be made on the basis of a comparison of the modern fire situation with that reconstructed from natural archives. Lake sediments is one of the best archives of the past fire intensity (Marlon, 2020).

2. Materials and methods

Lake Shira (54°30' N, 90°11' E) is located in Republic of Khakassia (Russia), 15 km from the regional settlement the Shira. The lake is oval in shape, 5.3 × 9.3 km in size, 35.9 sq. km in area, maximum depth 25.4 m (2021). A core 110 cm long was sampled using a UWITEC gravity sampler (Austria). The age of bottom sediments was previously determined for another core based on radioisotope analyzes (Kalugin et al., 2013).

Cores were compared by stratigraphic correlation of visually distinguishable layers. The analysis of charcoal particles was carried out in core sampling with a step of 1 cm based on the methods described in the works (Unkelbach et al., 2018; Anderson and Wahl, 2016). Sedimentation traps were installed seasonally from 2012 to 2019 at a depth of 20 m in the central deep part of the lake (N 54°30.350, E 90°11.350). Sedimentation traps were polypropylene cylinders, open at the upper end, 580 mm long and 103 mm in diameter. Sedimentary material from each trap, stored as a suspension in sealed plastic bottles, was thoroughly mixed and 100 ml was poured for analysis of charcoal. Samples of wet bottom sediments were kept in a deflocculating solution (6% sodium hexametaphosphate). After at least three hours, the samples were wet sieved through a tissue with a mesh size of 100 µm. The resulting residue was kept for 1 hour in 6% sodium hypochlorite for bleaching and again sifted through the same tissue. The residue was placed in a Bogorov chamber and viewed under a stereomicroscope in reflected light at 25x magnification. The sedimentary material of the traps was treated in a similar way, but without keeping in the deflocculating solution. Statistical analysis and plotting

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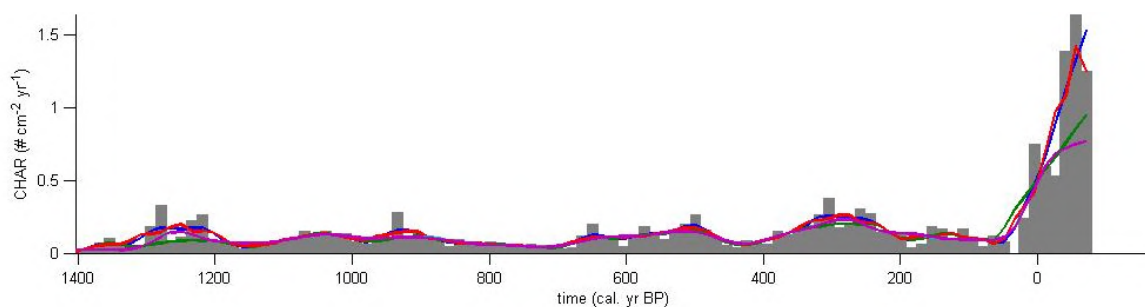


Fig. Dynamics of the flow of charcoal particles >100 micron into the bottom sediments of Lake Shira for the past 1400 years (0 means 1950 CE).

were performed using the CharAnalysis program (<http://CharAnalysis.googlepages.com>, Higuera et al., 2009).

3. Results and discussion

Charcoal particles >100 μm in bottom sediments are indicators of fires that occurred in a territory several kilometers adjacent to the lake (Unkelbach et al., 2018). Our results indicate that charcoal sedimentation flux sharply increased for the past ca. 100 yr (Fig.). This increase is consistent with the results for many lakes in the World and is presumably due to the current increase in anthropogenic impact, both as accidental and deliberate arson, and as burning wood and coal for heating buildings and summer camping fires in the area adjacent to the lake.

In all traps, charcoal particles of various shapes were found. These particles can be interpreted as the result of fires in the 10 km vicinity of the lake (Anderson and Wahl, 2016). The dynamics of flows showed a clearly pronounced seasonal dynamics with maxima in the period from October to May, and minima in summer and autumn. Obviously, in winter, the supply of charcoal from the burned fuel (coal, firewood) for heating dwellings in the surrounding villages increases significantly. However, in early spring, after the snow melts, the largest number of steppe fires is observed here, due to the presence of last year's dry grass. Thus, coals from two different sources - winter fuel combustion and spring fires - fall into the same October-May traps, so we cannot assess the contribution of each of the sources separately.

However, predominance of "particle" type charcoal indicates that the main contribution comes from fuel combustion. When burning steppe vegetation, one would expect the predominance of coals of the "grass" and "leaves" type, which is not observed in our case.

4. Conclusions

Our data show a significant contribution of anthropogenic factors to the sedimentation flow of charcoal particles in the Late Holocene, both as traces from burning fuel and traces from spring fires.

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Conflict of interest

The authors declare no conflict of interest.

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Paleolimnological reconstructions for Lake Arakhley (Central Transbaikalia, Russia) inferred from high-resolution reflection seismic data

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ABSTRACT. High-resolution seismic data (65 km profiles) have been used to study the sedimentary infill of Ivan-Arakhley lake system (Lakes Arakhley, Ivan and Shakshinskoe). It found that full limnological cycle bears only sediment cover of Lake Arakhley. Total sediment infill of Lake Arakhley is 6-7 m, and it was be divided into three sequences. The uppermost ~2.5 m of sediment cover was presented by a normal lacustrine filling. Lacustrine sediments began to form ca. 21 cal. ka BP. The lake was almost dried during the regression occurred between ca. 3 and 2.6 cal. ka BP.

Keywords: high-resolution seismic data, Ivan-Arakhley lake system, Transbaikalia, LGM, Holocene

1. Introduction

In present, there still is gap about structures of sediments cover of small lakes from Transbaikalia. Lake Arakhley belongs to the Ivan-Arakhley lake system (6 lakes), an is located on 955 m a.s.l. This area is 59 km², and 11x6.7 km in size. The lake is the largest freshwater body of Transbaikalia, however, knowledge about its limnology evolution is still rare. In our study, based on the analysis of high-resolution seismic data on the sedimentary infill of three lakes from the Ivan-Arakhley lake system, we attempt to reconstruct the evolution of the lakes as regional climate and geology proxy the Late Pleistocene-Holocene.

2. Materials and methods

Seismic data were collected using a Frequency Modulated (FM) sub-bottom profiler consisted of tree transducers that receive and radiate FM signal (frequency 1-10 kHz). Seven and 35 km of seismic profiled were obtained on Lake Arakhley, and 30 km of seismic profiled were obtained on Lakes Ivan and Shakshinskoe, in 2022. The FM profiler enables to study stratification of sedimentary layers with a resolution of up to 10 cm. For conversion of the acoustic travel time into depth, we assumed velocity of 1.45 m/ms in water and 1.5-1.6 m/ms for the uppermost unconsolidated sediments.

3. Results and discussion

3.1. Seismostratigraphic facies and subdivisions

Illuminated sediment cover is approximately 6-7 m and below seismic signal damped. According to characteristic of seismic signals, bulk sediment can be divided into three sequences. Thus from down to up, a lower part – the basement is chaotic unstructured high-amplitude reflections, acoustically un- or poorly stratified (Fig. 1). Thickness is approximately 1.5-2 m (deeper, seismic signal damped). It is most likely that reworked fluvial and eolian sediments represent these sediments. It is notable that there are two clear, high amplitude reflectors into the basement sequence. These reflectors are likely attributed with gaps in fluvial sedimentation.

The upper sequences indicate about a transition from a shallow to modern lake condition. Thus, the basement was overlapped by high-amplitude sub-parallel reflections in middle or hummock at distal part of the lake. This sequence can be related with shallow lake sediments (pLS) at began filling of the lake. The mean thickness of pLS is 1 m. There are packets of chaotic low-amplitude reflections embedded into packets of parallel reflections can be associated with a silty sand-rich mudslide, sandslide or river fan.

The upper sediment sequence (~2.5 m thickness) is thinly and regularly stratified, with good lateral

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continuity (longitudinal and transverse) (Fig. 2). This sequence are represented by low and high-amplitude sub-parallel reflections. However, the sequence (LS) can be divided into three units (Fig. 1). The unit-1 is characterised by high-amplitude reflectors, that it likely indicates about to enrich of sediments by coarse clastic materials. In contrast, the unit-2 is presented by low-amplitude reflectors and “transparent” in seismic records. We assume that the unit-2 is a high water-saturated lake sediment. The uppermost layer (the unit -3, ~20-30 cm thickness) is characterised by high-amplitude reflectors. It is notable, the upper parts of units 1 and 2 were eroded, and the unit 3 overlap this erode surface (Fig. 3). The drop of lake level was approximately by 12-12.5 m relative to the modern. The lake was practically full dried, and 1-3 m depth along the axial part, during this lowstand.

In general, this reflection pattern of sequence – LS can be interpreted as normal lacustrine filling, and its thinning seems to show that the lake depths gradually increased.

Seismic patterns of Lakes Ivan and Shakshinskoe are presented by chaotic unstructured high-amplitude reflections. Reflectors related with lacustrine sediments were not found. Lacustrine sediments likely was denudated during the regression marked in Lake Arakhley by the unit 3. However, in records from Lake Shiksha, there are two reflectors similar to those from the basement of Lake Arakhlei.

3.2. Paleo-reconstructions

Age estimation and regional pale-reconstruction based on investigation of bottom sediment Lake Arakhley are still rare. Our interpretation of seismic pattern and age estimations based on Reshetova et al. (2013) and Solotchina et al. (2018). The uppermost 1.27 m from lateral part of the lake was dated by 15 cal. ka BP (Solotchina et al., 2018). There are the pollen record and radiocarbon age estimation for the core located near discussed seismic profile showed in figure 2, the uppermost 1.44 m of the LS was formed during 13 cal. ka (Reshetova et al., 2013). In addition, this core was sampled from the part of lake with lacustrine condition during the regression described above. Thus, the depth-age is practically line, and it can be evidence of the absence of a gap in sedimentation between the unit-3 and 2.

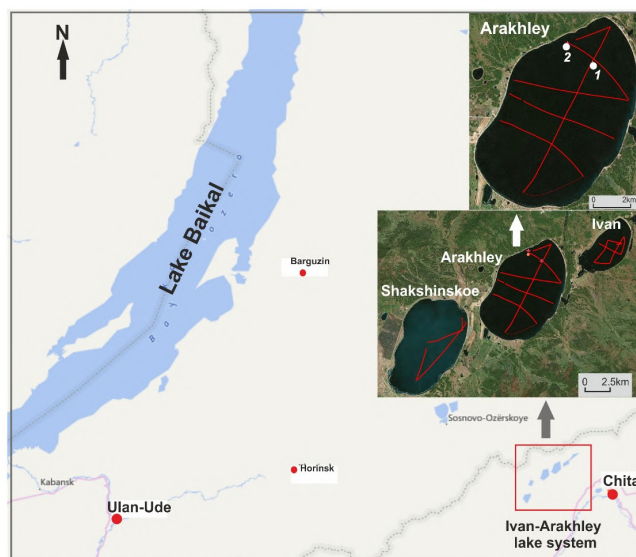


Fig.1. Location of studied lakes. Red lines - seismic profiles, white circles 1 - the core from Solotchina et al. (2018), 2 - the core from Reshetova et al. (2013).

If the line depth-age model is correct then the unit-2 and 3 likely began to form ca. 13.4 and 2.6 cal. ka BP, respectively. The extrapolated age for the boundary between the pLS and unit-1 (~2.5 m below sediment surface, bss) is ca. 21 cal. ka BP. However, actual age of this boundary may be somewhat younger, because the unit-1 was composited more coarse sediment compare to the unit-2a and sediment rates likely were higher. Thus, the unit-1 formed during the Late Glacial Maximum of Pleistocene (LGM). The pollen data from 1.4-1.6m layers also indicated about cold and dry air condition related with the LGM (Reshetova et al., 2013).

It is surprised, that lacustrine conditions (the pLS and unit-1) were during the LGM. In addition, lacustrine sediments dated by ca. 15 cal. ka BP have been reported by Solotchina et al. (2018). For instance, significant climate changes in Baikal region happened ca. 22 and 17.5 ka BP and small lakes dramatically reduced or dried (Chensky et al., 2020). It seems that Lakes Ivan and Shakshinskoe were dry at the LGM, because there are no lacustrine sediments. Air condition of the LGM was characterized as dry, however, high content of Caryx-Poaceae assemblages in pollen record can be attributed with water-saturated soil due to season

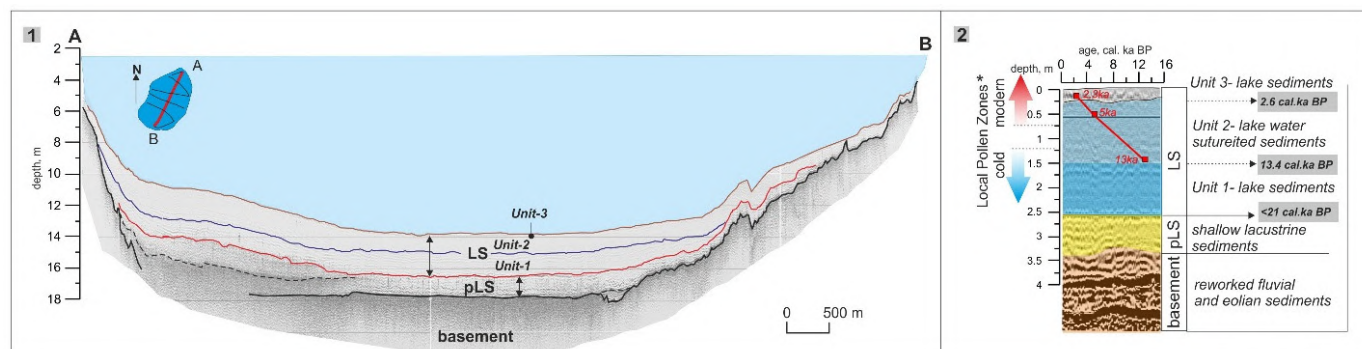


Fig.2. Seismic stratigraphy of Lake Arakhley. 1 - axial profile along sediment fill of Lake Arakhley. 2 – facies interpretation of seismic sequences, local pollen zones and depth-age model from Reshetova et al. (2013).

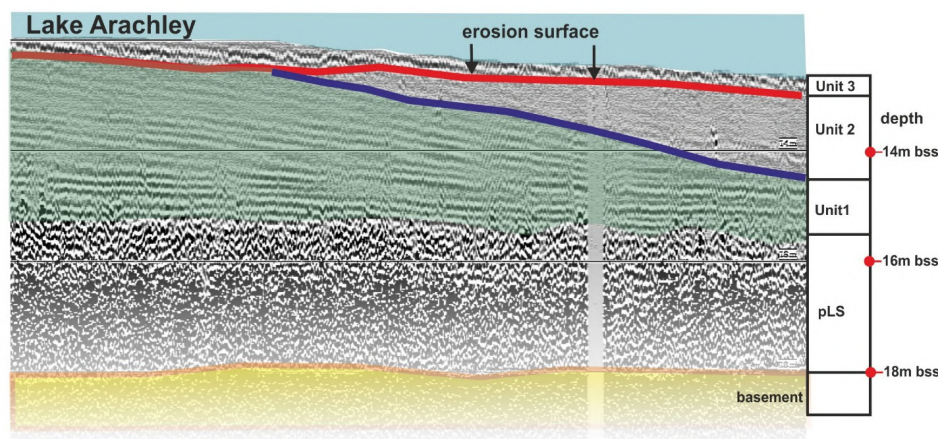


Fig.3. The example of the lowstand of Lake Arakhley occurred between 3 and 2.6 cal. ka BP.

thawing of active layer of permafrost (Reshetova et al., 2013). It is possible, a positive water regime of Lake Arakhley was due to supply of the thawing water into the lake during LGM. In addition, lake ice cover could not be completely break due to a short summer, as a result, evaporation from the lake was insignificant, and lake was stable by thawing water.

The modern regional climate and landscape features are forming since *ca.* 6.5 cal. ka BP (0.7 m bss) (Reshetova et al., 2013). Episode of the lowstand of lake occurred before 2.6 cal. ka BP likely was short because there are no deep erosion cuts and thickness of eroded part of the unit 2 was about 20-cm. Regional oxygen isotope records marked change at *ca.* 3-2.5 ka BP (Kostrova et al., 2013). We assume that the lowstand happened between 3 and 2.6 cal. ka BP.

There are no bodies of a silty sand-rich mudslide, sandslide or river fan that evidence about high inflow of suspended material into the lake after the lowstand. In this reason, acoustical “hard” reflectors of the unit-3 can not be explained by a high content of allochthonic clastic material. We assume, that these acoustic features of the sediment indicate low rate of rise up to modern of the lake level.

4. Conclusions

The sedimentary infill of Lakes Arakhley, Ivan and Shakshinskoe were studied based on 65 km profiles of high-resolution seismic data. It was found that sediment records of Lake Arakhley contents sediment sequences from the beginning lacustrine condition to modern status. However, there are no representative lacustrine sediments in Lakes Ivan and Shakshinskoe. Found thickness of sediment cover of Lake Arakhley is 6-7m. The uppermost ~2.5 m of sediment cover was presented by a normal lacustrine filling showing gradually increase of lake level. Estimate age of the beginning is *ca.* 21 cal. ka BP. Lake level dramatically dropped by 12-12.5 m relative to the modern, between *ca.* 3 and 2.6 cal. ka BP.

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Conflict of interest

The authors declare no conflict of interest.

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Late Holocene vegetation history of the Western Caucasus inferred from high-resolution pollen record from Lake Karakel

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ABSTRACT. The paper presents a new paleoecological evidence for the last 2200 years based on high resolution pollen record and detail radiocarbon dating, obtained from Lake Karakel (Teberda River valley, Western Caucasus). The obtained results showed that vegetation changes from 2200 to stage 1200 cal, yr BP occurred under a climate warming and increase of humidity. The Medieval Climatic Anomaly-MCA (ca. 1200-880 cal. yr BP) was characterized in this region by the predominance of broadleaved forests. The MCA was followed by a cold interval of the Little Ice Age (ca. 880-120 cal yr BP) that marked by expansion of pine, spruce and fir forests to the lower altitude the present time.

Keywords: Caucasus, palynology, Teberda, paleolandscapes, reconstruction

1. Introduction

The Late Holocene vegetation and climate history in mountainous regions are characterized by high temporal and spatial variability (PAGES 2k Consortium, 2017), therefore regional paleoenvironmental reconstructions may be useful in unraveling the ecosystem response to ongoing climatic change. In this case the proxy records revealed from mountainous lakes holds a great potential for paleovegetation and climate studies.

The present study is focused on the mid-altitude Lake Karakel is located in the Teberda River valley, Western provinces of Great Caucasus. The studies of mountain lakes in the Western Caucasus began by research group from the Institute of Geography of Russian Academy of Science about ten years ago exploring Lakes Karakel and Donguz-Orun (Chepurnaya, 2014; Solomina et al., 2014). The previous pollen record from Lake Karakel covered the entire Holocene with a hiatus of ca. 2000 years in the middle Holocene. Annually laminated sediments in Lake Donguz-Orun near Terskol village, Kabardino-Balkaria cover <1000 years (Aleksandrin et al., 2018). Despite the large amount of the obtained pollen data, the Late Holocene environmental history remained poorly understood.

Our study provides new paleoecological evidence for the last 2200 years based on high resolution pollen record supported by detail radiocarbon dating, obtained from Lake Karakel.

2. Materials and methods

Lake Karakel (N 43 26' 12,13" E 41 44' 34,72") at altitude 1335 m a.s.l. (above sea level) is dammed by an old moraine in the Teberda River valley. The lake is 6-8 m deep and occupies an area of 140x280 m. The lake is surrounded by a sparse pine forest.

Three overlapped lacustrine sediment cores up to 180 cm long retrieved from Lake Karakel in 2010 and 2016. The present study is focused on the 76 cm long core obtained in 2016 that includes the uppermost dark brown to black organic reach sediments.

Radiocarbon dates from the core obtained in 2010 together with the new ones were used for creating of the age-depth model. In total 10 AMS radiocarbon dates provide the chronological control for the sedimentation rate. Radiocarbon dating was performed in the Laboratory of radiocarbon dating and electronic microscopy at the Institute of Geography (Russian Academy of Science, Moscow, Russia) and the Center for Applied Isotope Studies at University of Georgia (USA). The ¹⁴C dates were calibrated using the program Calib 8.2, the calibration dataset Intcal20 (Reimer et al., 2020). Age-depth models were constrained using the Bayesian-based algorithm Bacon in the R language environment.

The sediment core was subsampled for pollen analysis with 1 cm interval. Samples (1 cm³) were prepared following modified method by Grichuk and Zaklinskaya (1948). Calculation of pollen percentages

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was based on the total terrestrial pollen sum, i.e. arboreal pollen (AP) plus non-arboreal pollen (NAP) without aquatic plants and spores. A minimum of 700 pollen grains per sample were counted (AP+NAP). Pollen diagram was constructed using the programs Tilia and TGView.

3. Results and discussion

According to an age-model based on the radiocarbon dates the uppermost 76 cm of the sediment sequences was formed about 2200 cal yr BP (Subatlantic period of the Holocene) with the accumulation rate of 0.22-0.23 mm/year.

The pollen diagram for Lake Karakel was divided into 7 local pollen assemblage zones (LPAZ), corresponding to the main phases of vegetation development (Fig.).

LPAZ 1 (76-65 cm; 2200-2000 cal yr BP). Pollen assemblages are characterized by a relatively high NAP content (up to 35%) dominated by *Poaceae* and *Asteraceae* (*Artemisia*). Pollen values of arboreal taxa increase from 65 to 90% towards the upper part of the zone. *Pinus* pollen is the most abundant. The permanent components of pollen assemblages is *Alnus*, *Corylus* and *Betula* sect. *Albae*. Pollen of broadleaved species (*Quercus*, *Carpinus*, *Fagus*) and coniferous trees such as *Abies* and *Picea* occur in a minor quantity. Pollen of light demanded plants as *Hippophaea* and *Helianthemum* sp. were registered.

Pollen assemblages were obviously influenced by vegetation of several types of landscapes. Meadows were most likely confined to the southern, south-eastern and south-western slopes of the Teberdy River valley. The slopes of the northern and adjacent expositions were occupied by broad-leaved forests mainly of

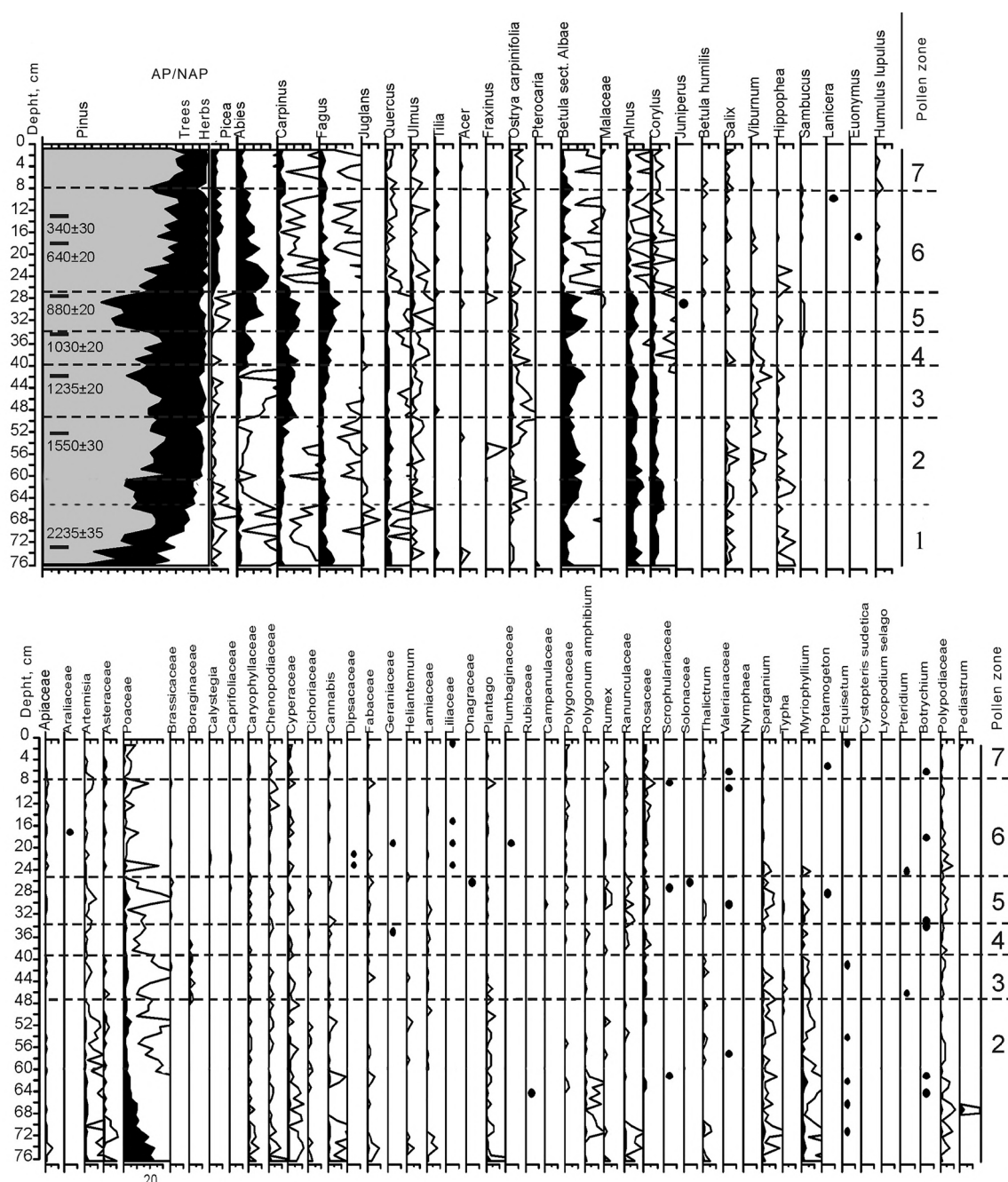


Fig. Pollen diagram of Karakel Lake deposits (AP + NAP = 100%). Age, C14 years BP.

beech and oak with the participation of coniferous species - spruce and fir. Besides, composition of pollen assemblages reflects an intrazonal vegetation, which included *Pinus*, *Betula*, *Salix* and *Hippophaea*, which settled mainly along the river bank and outflow of the ravine proluvium, affected by cold air flows descending from glacial covers and mountain ranges (Bagrova and Drozdov, 2010).

LPAZ 2 (65-49 cm, 2000-1500 cal yr BP). AP value increased from 80% in the lower part of the zone to 90% in its middle and upper parts. *Pinus* pollen still dominates in the AP group (50-70%), however the noticeable peaks of *Betula*, *Alnus* and *Corylus* pollen were detected. Broadleaved species (*Carpinus*, *Quercus*, *Fagus*, *Ulmus*) are not abundant, *Picea* and *Abies* pollen values a little declined. *Hippophaea* pollen became more frequent at the depth between 62 and 60 cm.

Changes in pollen assemblages indicated an afforestation of treeless areas. A rather high content of birch pollen in the spectra and the presence of *Hippophaea* pollen, which are early succession plant species, may indicate the active catastrophic geomorphological processes, such as avalanches, landslides, etc.

LPAZ 3 (49-40 cm, 1500-1200 cal yr BP). The zone was marked by first peak of *Carpinus* curve and increase of *Fagus* pollen values. AP value grew to 95%. Pollen assemblages revealed a change in the composition of broadleaved forests with the leading role of *Carpinus* and *Fagus*. The proportion of *Corylus* in the undergrowth declined, suggesting a greater crown density of forests compared to the previous stage.

LPAZ 4 (40-34 cm, 1200-1000 cal yr BP). *Abies* pollen value increases from 1 to 10%, The proportion of *Pinus* raised to 75%, while *Carpinus* and *Fagus* pollen value decrease to a few percent.

LPAZ 5 (34-27 cm, 1000-880 cal yr BP) Assemblages are characterized by noticeable peaks of *Abies* (up to 20 %) and *Fagus* (up to 10%) curve and second peak of *Carpinus* (up to 13%), while *Pinus* pollen value decreased from 75 to 50%.

Pollen assemblages of the LPAZ 4 and 5 suggest a successive development of coniferous-broadleaved forest belt with high abundance of *Carpinus*, *Fagus* and *Abies* which could be coincided with the Medieval Climatic Anomaly (MCA, ca. 900-1350 C.E. (common era); PAGES 2k Consortium, 2017).

LPAZ 6 (27-8 cm, 880-120 cal yr BP) There is a noticeable decrease in *Carpinus* and *Fagus* pollen percentages with increase in *Pinus*, *Abies* and *Picea* pollen values. The proportion of NAP group decreases to a few percent. Probably, climatic cooling of the Little Ice Age (LIA, AD 1450–1850 C.E.; PAGES 2k Consortium, 2017) encouraged the downward movement of beech-fir forests with the participation of *Pinus*, and *Picea*, typical for modern high-altitude woodlands near the timberline.

The previous studies of pollen and chemical element composition (Br) of the sediment sequences of the Karakel Lake revealed three LIA cooling phases in 1250-1400, 1500-1630 and 1750-1880 C.E. (Chepurnaya, 2014; Solomina et al., 2014).

Comparison of obtain data with pollen records

from the Rybnoye Lake (Kvavadze and Efremov, 1996), located in 50 km north-west from the Karakel Lake at altitude 2156 m a.s.l. showed a similar pattern of broadleaved pollen dynamics and rather synchronous phase of the MCA and LIA.

LPAZ 7 (8-0 cm, 120 cal yr BP – present). Pollen value of *Picea* and *Abies* decrease to a few percent, while *Carpinus* and *Fagus* pollen value increased. *Pinus* and *Betula* pollen values increased noticeably indicating and occurrence of pine and pine-birch forests on moraine ridges in river valleys and human induced vegetation disturbance.

4. Conclusions

Palynological analysis and radiocarbon dating of sediments from Lake Karakel allow us to discuss vegetation dynamics of the Western Caucasus during the sub-Atlantic stage of the Holocene. Vegetation changes from 2200 to stage 1200 cal. yr BP occurred under the climate warming and increase of humidity. The Medieval Climatic Anomaly (ca. 1200-880 cal yr BP) was characterized in this region by the predominance of broadleaved forests. The MCA was followed by a cold interval of the Little Ice Age (ca. 880-120 cal yr BP) that marked by expansion of pine, spruce and fir forests to the lower altitude at the present time.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Lake sediments as archives of early anthropogenic impact on the landscapes of the Vishtynets Upland (Kaliningrad region RF, SE Baltic)

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ABSTRACT. The study of lake sediments contributes to the understanding of the types and intensity of anthropogenic impact on the landscapes of the Vishtynets Upland (Southeastern Baltic) in prehistoric times and the Middle Ages by combining available paleoecological and archaeological information. The results of lithological, paleobotanical and geochemical studies, together with archaeological data, have allowed a deeper understanding of the dynamics of anthropogenic impact in the area, including the emergence of agriculture and ancient metallurgy. Archaeological data testify to the presence of human activity on the Vishtynets Upland from the Late Paleolithic, and applied paleolimnological analysis revealed the first signs of anthropogenic impact, starting from the Late Mesolithic and Neolithic, and intensifying it from the Bronze Age.

Keywords: lake sediments, anthropogenic impact, palaeoecology, prehistory, emergence of agriculture, emergence of metallurgy

1. Introduction

A review of archaeological and paleo-environmental evidence shows that during at least 12000 years, all human societies have transformed the environment using land use practices, including forest burning, hunting, domestication, cultivation, and others (Ellis et al., 2021). Anthropogenic changes in the environment have regional and temporal differences, and both major and minor traces of anthropogenic impact are recorded in numerous natural archives, such as lake sediments. The study of the lakes situated in the southeastern Baltic provides a new insight into the history of nature and population interaction in this part of Europe during the Holocene.

2. Materials and methods

The main objects of palaeolimnological research in the Kaliningrad region are lakes located on the Vishtynets Upland (the northern part of the Baltic Moraine Ridge). In 2010 – 2015, the coring on Lakes Kamyshovoe (N 54°22'; E 22°42'; 192 m a.s.l.) and Chistoe (N 54°38'; E 22°72'; 202 m a.s.l.) took place. Sampling was carried out from the raft and from the ice using Russian peat corer (sampler diameter 5 cm, length 1 m); cores of bottom sediments with a length of

9.6 m (Kamyshovoe) and 4.1 m (Chistoe) were selected. The lakes have been studied in detail in terms of lithology, geochronology and palynology (Druzhinina et al., 2022). For Lake Kamyshovoe, the complex of analytical methods also included diatom, chironomid, geochemical, paleomagnetic, and paleoisotope analyses (Druzhinina et al., 2020).

3. Results and discussion

The obtained palynological and geochemical data have shown that the first signs of human impact on landscapes date back to the Early Mesolithic (approximately from 10,000 cal yr. BP), indicating the presence of local deforested areas. Pollen from plants-indicators of open habitats and pastures, as well as *Pteridium* and *Corylus*, combined with elevated Ba and Sr values as indicators of fuel burning, suggests the deliberate burning of forests for the enhancement of hunting and mobility, and probably for the propagation of edible plants. The correlation of microcharcoal and pollen data for the Neolithic reveals several peaks of anthropogenic activity on the Vishtynets Upland: ~ 6300, 5900, 5700, 5200, 4700, 4300, 4000 cal. BP. The study also showed that the cultivation of *Cerealia* in this area began no later than 5100 cal BP.

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Geochemical data from Lake Kamyshovoe probably testify the emergence of ancient metallurgy in the region and its influence on the palaeoenvironment. The analysis of lake sediments revealed increasing concentrations of Cu, Ni, Pb, As and, in general, a group of heavy metals from depths corresponding to the Bronze Age. A clear correlation of the Ni and Pb content peaks with the maximum values of microcharcoal was also traced. Preliminary results show that in the Vishtynets Upland, ancient metallurgy could have been an environmental transformation process since at least the Iron Age (Druzhinina et al., 2022).

4. Conclusions

Our study emphasises the effectiveness of applying an integrated approach to study lake sediments as archives of data on early anthropogenic impact on the landscapes. According to palaeolimnological data, the first signs of anthropogenic impact in the the Vishtynets Upland appear in the Mesolithic and essentially increase from the Bronze Age. The main types of anthropogenic activity during prehistory traced by lake sediment study were deforestation, early agriculture and probably metal smelting.

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Conflict of interest

The authors declare no conflict of interest.

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Northern Eurasian large lakes level changes in the context of late Quaternary climatic and glacial history

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ABSTRACT. During the last years major progress in the reconstruction of the climatic and environmental history of Northern Eurasia has been made within the scope of the Russian-German project PLOT. The project aimed at investigating the regional responses of the quaternary climate and environment on external forcing and feedback mechanisms along a more than 6000 km long longitudinal transect crossing Northern Eurasia. The well-dated record from Lake El'gygytyn used as reference site for comparison the local climatic and environmental histories. Seismic surveys and sediment coring up to 54 m below lake floor performed on Ladoga Lake (North-West of Russia), Lake Bolshoye Shchuchye (Polar Ural), Lake Levinson-Lessing and Lake Taymyr (Taymyr Peninsula), Lake Emanda (Yana Highlands). Here, we present the major results of the project with a special focus on lake-level fluctuations and forcing mechanisms.

Keywords: Northern Eurasian large lakes, Late Quaternary environments, lake-level changes

1. Introduction

Much progress has been made recently in the reconstruction of the climatic and environmental history of Northern Eurasia based on exploring and retrieving long sediment records from lakes. The most prominent example is Lake El'gygytyn that was the subject of an international ICDP drilling project that resulted in the recovery of the longest continuous palaeoclimatic and palaeoenvironmental record for the terrestrial Arctic covering the last 3.6 million years (Melles et al., 2012; Brigham-Grette et al., 2013).

Russian-German project PLOT (Paleolimnological Transect) aimed at investigating the regional responses of the quaternary climate and environment on external forcing and feedback mechanisms along a more than 6000 km long longitudinal transect crossing Northern Eurasia using the well-dated record from Lake El'gygytyn as reference site for comparison the local climatic and environmental histories.

2. Materials and methods

In order to reconstruct the climatic and environmental history during Late Quaternary times seismic surveys and sediment coring performed on five lakes, which together with Lake El'gygytyn form a more than 6000 km long longitudinal transect across northern Eurasia.

A multi-channel, high-resolution seismic reflection survey using a Micro-GI airgun and Innomar sediment echo sounding system were used for obtaining large-scale information on the depositional and post-depositional histories, and for selecting the most appropriate locations for coring.

Sediment coring performed by using an improved UWITEC percussion piston corer.

For the reconstruction of the sedimentary processes a range of bulk analyses carried out on the sediment cores, including whole-core MSCL logging (physical properties, 1 cm spacing), half-core XRF

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scanning (chemical composition, 0.2 to 5 mm spacing), thin section microscopy (microstructures, irregularly) as well as water contents, grain-size distributions, organic and inorganic geochemistry (regular, every 4 to 16 cm). The basic chronologies established by means of ^{14}C AMS and optically stimulated luminescence (OSL).

The paleoclimatological reconstructions particularly rely on palynological and diatom analyses.

3. Results

Major results recently published in special issues of journals *Boreas* (Melles et al., 2019 and references therein) and *Journal of Quaternary Science* (Melles et al., 2022 and references therein).

During the pilot stage of the project in 2013 about 1500 km of seismic profiles were performed and two long (18 m and 22 m) sediment cores were retrieved in northern part of Lake Ladoga that is largest European lake located in North-West of Russia. In summer 2016 54 m-long sediment core was obtained in the central part of 130 m deep Lake Bolshoye Shchuchye located in Polar Ural. During 2016 and 2017 seismic surveys and sediment coring performed in Taymyr Peninsula on lakes Levinson-Lessing (47 m-long sediment core) and Taymyr (14 m and 16 m-long sediment cores). In summer 2017 sediment echo sounding and coring (6 m-long sediment core) were performed on Lake Emanda (Yana Highlands).

4. Discussion and conclusions

New results concerning Late Quaternary lake-level fluctuations obtained for lakes Ladoga (Gromig et al., 2019; Lebas et al., 2021), Bolshoye Shchuchye (Lenz et al., 2022a), Levinson-Lessing (Lebas et al., 2019; Lenz et al., 2022b), Taymyr (Gromig et al., 2022), Emanda (Baumer et al., 2021) and El'gygytyn (Fedorov et al., 2019) in addition to partly available information in the literature allow to make following main conclusions:

1. In the western and central sectors of Northern Eurasia strongly affected by Late Quaternary Ice Sheets large lakes level changes do not directly correlate with climatic history but more controlled by ice margin position.
2. In the eastern sector of Northern Eurasia large lakes level changes shows prominent correlation with climatic history.
3. The longest lake-level history is reconstructed for Lake El'gygytyn (since MIS 7). Reconstruction shows that long-term lake-level history during the Middle and Late Pleistocene is the mean summer temperature but short-term lake-level changes at the transition from the last glacial to the Holocene and within the Holocene, in contrast, are controlled not only by the temperature but also by the local precipitation.

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Conflict of interest

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Lake Chukhlomskoe in the Late Pleistocene and Holocene (Kostroma region, Russia)



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ABSTRACT. The article discusses the first results of geomorphological and paleolimnological study of Lake Chukhlomskoe (Kostroma region). We analyzed the topography of the lake bottom using new bathymetric data from 2021 fieldwork. The structure of the lake basin slopes was studied using hand drilling. Analytical characteristics of the bottom sediments core (grain size distribution, loss on ignition, magnetic susceptibility, AMS-dating and palynological data) are presented. The distribution of organic matter, carbonates and particle size by depth allow us to correlate the bottom sediments of Lake Chukhlomskoe with the sediments of other well-studied large lakes (Belaya Struga, Galichskoe and Seliger).

Keywords: paleolimnology, paleoarchives, relief, lake deposits, Lake Chukhlomskoe

1. Introduction

Lake Chukhlomskoe is located in the northern part of the Kostroma region, on the elevated Galich-Chukhloma ridge (the watershed of the Kostroma and Unzha rivers). It is one of the largest and most ancient lakes in the center of the East European Plain, along with lakes Pleshcheevo, Nero and Galichskoe. Their location south of the boundary of the last Valdai glaciation (Map of Quaternary..., 1972) suggests that the age of lake sediments may exceed 130 thousand years.

Lake Chukhlomskoe has a relatively small catchment and compact size – its area is about 48.7 km² with a maximum length from NW to SE of 8.8 km and a maximum width from SW to NE of 7.6 km. All tributaries are small rivers. According to the rate of external water exchange, the lake belongs to medium- and low-flow, autochthonous processes prevail in it. The removal of solid runoff, nutrients and pollutants are difficult. The lake is highly trophic. There is a process of active eutrophication of the lake (Timofeeva and Yuhno, 2019). In 1963, on the Veksa River, flowing out of the lake, a sill overflow dam was built (upper pool height 150 m asl, lower pool height 148 m asl). It was renovated in the 2010s.

The lake's geomorphological position and its basin's morphometric characteristics create the

prerequisites for stable and continuous sedimentation, which is very important for environmental paleoreconstructions since the loss of information from such a paleoarchive is minimized.

Until now, there was no reliable data on the age and composition of the sediments of the Chukhlomskoe lake basin, which makes it the least studied among the other mentioned lakes.

The history of the study of Chukhlomskoe lake includes several stages: 1) in the 1920-30s, gyttja deposits were evaluated, but the results were published only in small descriptive articles (Chernov, 1930; Shturm, 1932). Since the 1980s, the works have been mainly devoted to the lake's ecology and fishery problems (Baranov and Tereshin, 1981; Cherednichenko, 1987). In 1993 there was one more gyttja deposits study (Gurin, 1993) without any multi-proxy analytics and publications. There are few modern studies, and they are mainly devoted to the lake's ecology (Sirotnina and Vorontsova, 2016; Timofeeva and Yuhno, 2019).

2. Materials and methods

Three fieldwork expeditions were carried out to study the basin and bottom sediments of Lake Chukhlomskoe. In winter 2021, we verified the archival map of 1927-28 by manual lotting and drilled

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two boreholes (using the Livingston Piston Sampler) at different depths: Chu13A (7 m long) at a depth of 4.5 m and Chu7A (9 m long) at a depth of 2.6 m. Also, for Chu13A borehole, the upper weakly consolidated part of the sediment was selected according to the method of E.A. Konstantinov (2019).

In summer 2021, a bathymetric survey of the entire water area of the lake was carried out using a motor boat and two echo sounders – Deeper Pro+ and Lowrance HDS 9. We obtained more than 50000 depth measurement points, which allowed us to make the first reliable Chukhlomskoe lake's bottom relief model. Also, two drilling profiles were made on the slopes of the lake basin: 14 boreholes with an Eijkelpamp hand drill with a depth of 1.4 to 3.6 m and one pit with a depth of 1.76 m.

In winter 2022, we made 54 points with probe drilling, and as a result two boreholes were drilled: 13.65 m long on the background surface with the depth of 2.6 m (Chu22-39A) and 5.1 m long on the transverse profile near the area of the Veksa river head (Chu22-16A, which reveals loamy deposits with gravel inclusions). Also, presumably gas outlets were found on the ice surface.

The samples of the bottom sediments were analyzed at the Laboratory of Paleoarchives of the Natural Environment of the Institute of Geography RAS. Samples for AMS-dating was prepared at the Center for Collective Use, Laboratory of Radiocarbon Dating and Electronic Microscopy, Institute of Geography RAS and measured at the Center for Applied Isotope Studies, University of Georgia (USA). The particle size distribution of the deposits (with a step of 5 cm) was performed on a Malvern Mastersizer 3000 laser diffractometer. Loss on ignition (LOI) was measured according to the method proposed by O. Heiri et al. (2001). Mass magnetic susceptibility (MS) was measured using a ZH Instruments SM 150 L instrument at low frequency (500 Hz). Samples were also taken for diatom and palynological analysis to characterize paleoecological and paleoclimatic conditions. These parameters are currently being processed (except for four palynological samples of Chu13A core). Analysis for the content of radioactive isotopes (^{137}Cs , ^{210}Pb) was made at the Radiochemistry Division of the Chemistry Department of the Moscow State University.

3. Results

Our bathymetric map analysis results showed that the deepest zone has the shape of two hollows, diverging from the center of the lake towards the city of Chukhloma (to the southeast). The maximum depth in this zone (and the entire lake) reaches 5.44 m. The lake's average depth is 2.38 m (median – 2.26 m, modal – 2.24 m). Depths of 2.1-2.3 m occupy 37% of the area and depths of 1.9-2.6 m – 66.33%. According to the depth distribution histogram, it can be seen that there are two steps – 2.0-2.4 m and 1.5-1.8 m. The hollows have morphological features of fluvial forms: smooth bends and sustained width. At the same time, these

forms are enclosed – i.e. they are interrupted, which is impossible for normal channel forms. In the bottom topography, there are no signs of overdeepening (hollows) in the northern part of the lake, where the Veksa River flows out of it. In the structure of the sides of the Chukhloma lake basin, there are no signs of a level rise above the present level during the Upper Pleistocene and Holocene. The upper layer of the bottom strata is organic silt (gyttja) of brown-olive color with a thickness from 2 to 5 m. Unstratified gray mineral silt (loam) lies below.

Chu13A core (4.5-11.45 m) was fully investigated by laboratory and analytical methods. Curves of changes in the material composition make it possible to identify the stages of changes under the conditions of sedimentation. From a depth of 6.4 m upsection, an increase in the content of organic matter (LOI 550) begins, then there is a slight decrease, and again a sharp increase from a depth of 5.4-5.5 m. Magnetic susceptibility decreases with an increase in the amount of organic matter in the sediment. The carbonate content clearly shows a peak at a depth of 5.4-5.7 m, which is preceded by a stage of increasing sediment size at a depth of 5.9-6.1 m. Four samples have palynological characteristic. The lower samples from a depth of 8 and 10 m characterize the conditions of the late pleniglacial (after LGM) – periglacial steppe with the participation of a few cold-resistant tree species in minimal numbers. This is confirmed by AMS-dating from depths of 8.1 and 9.85 m (22320 ± 60 cal BP and 23110 ± 110 cal BP, respectively). A sample from a depth of 6 m characterizes the conditions of the late glacial period – birch periglacial forest-steppe with spruce and has an age of 18000 ± 90 cal BP. A sample of the upper layer from a depth of 5 m characterizes the middle Holocene – forest, spruce, and broad-leaved species (mainly oak) with a lot of birch pollen (between 5110 ± 110 and 5130 ± 100 cal BP). The core bottom at a depth of 11.4 m has been dated as 25460 ± 110 cal BP. The pattern of the curves of analytical characteristics in the remaining boreholes below 4.5 m is identical to Chu13A. But there is a large thickness of organic gyttja at the upper part, which indicates that in the Chu13a borehole, which was drilled in a hollow, the upper part of the sediment was eroded. The result of the assessment of the content of radioactive isotopes ^{137}Cs and ^{210}Pb showed low rates of modern sedimentation. All the cores have layers with porous material which means that there is a process of gas production in the sediment.

4. Discussion and conclusions

The hollows were developed in Holocene; its probable mechanism of origin is erosion due to the bottom current resulting from the release of gases/springs with the participation of wind surge in case of strong winds and the fact that the natural depth of the basin was at least 1 m less before the dam's construction. The lake is a potentially good archive for studying Late Pleistocene and Holocene sediments with a small catchment area and a slow flow of material

brought by rivers which suggests to find regional signal of landscape and climate change. A sharp peak in the content of carbonates at the end of the Late Glacial (interval 5.45–5.69 m in Chu13A core) and the peak in the content of the sandy fraction preceding it mark the regional patterns of sedimentation for lakes in the center of the Russian Plain (Konstantinov et al., 2021). The results of analyzes for all cores are comparable to each other, the results are reproducible. There is a good potential for correlation with the NGRIP oxygen isotope curve.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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A multi-proxy study of Holocene environmental and climate change in the Pechora Delta

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ABSTRACT. The Arctic and subarctic regions have been the focus of a great deal of research during the recent years. Their high-latitude areas are thought to play a crucial role in climatic forcing and, thus, may be particularly sensitive to climate change. Arctic freshwater ecosystems are especially susceptible to the negative consequences of global environmental change drivers. Paleoclimatic investigations provide a better insight into the climate and environmental situation of certain regions and water objects in the past and help to predict their future changes, as well as to identify the development trends of the Earth's climate as a whole. The multi-proxy study of 96-cm long sediment core obtained in Lake Arcto-Pimberto (68°26.114' N, 053°32.311' E, the Pechora River delta, Nenets Autonomous Okrug) reflect regional paleoecological and climate changes in the north of the Eastern European plain over the last 6400 year. Based on the subfossil Cladocera, diatom and palynological analysis of the bottom sediment of the arctic lake Arkto-Pimberto, we received preliminary information on environmental and climatic changes, as well as on changes in vegetation character in the area around the water body.

Keywords: subfossil cladoceran community, pollen, spores, diatoms, Pechora River delta, Arctic lake

1. Introduction

Lake sediments contain a variety of organic and inorganic remains that may be used to track the history of a lake or its catchment. Diatoms, cladocera, and remains of plants are used as indicator groups in paleoecological studies (Frolova, 2018; Nigmatullin et al., 2021). The aim of this work is a paleoecological reconstruction of the development of the Arctic lake Arkto-Pimberto using multi-proxy analysis.

2. Materials and methods

The investigated lake is located in the delta of the Pechora River, the largest river in the European North of Russia that flows into the Barents Sea. The region is an alluvial plain consisting of numerous large and small islands. A 96-cm-long core of bottom sediments was recovered from the central part of Lake Arkto-Pimberto during the summer expedition in 2018. For paleobiological analysis were used samples taken at 1-2 cm intervals.

For pollen analysis treatment of the samples was carried out with the help of the Faegri-Iversen method, but without the acetolysis stage (Faegri and Iversen, 1989). All diatoms samples were processed by the standard methods using 37% hydrogen peroxide as an

oxidant of the organic matter present in the samples, including 10% HCl treatment in order to remove calcium carbonate, followed by rinsing with distilled water (Battarbee, 1986). The sediment samples for Cladocera analysis were studied using the standard techniques (Korhola and Rautio, 2001; Szeroczyńska and Sarmaja-Korjonen, 2007). Microscopic examinations were made at x100-400 magnification under a light microscope Axio Imager A2 (Carl Zeiss, Germany).

3. Results and discussion

As a result of the diatom study, 113 diatom taxa comprising 44 genera were identified in the fossil diatom flora. The ecological and geographical analysis of the species composition showed the dominance of Holarctic, benthic, and alkaliphilic species with the abundance growth under moderate temperatures. With the help of the cluster analysis, the entire core was divided into three zones based on the presence of diatom taxa and their relative abundance. The first zone corresponds to the stage when the lake was characterized by the mass development and diversity of diatoms, thereby reflecting the period of the high water level and the formation of a deep and less mineralized water body. Diatoms were present in small number or absolutely absent in the middle layers of the core. In the

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upper part of the core, there is significant an increase in the number of diatoms.

A total of 16 cladoceran taxa were found in sediment. In general, the crustacean remains were distributed evenly throughout the core. *Bosmina (Eubosmina) longispina*, the cold-water taxon characteristic of oligotrophic water bodies, was absolutely dominant in all stratigraphic zones. The complex of subdominant species included *Chydorus cf. sphaericus*, *Alona affinis*, and *Rhynchotalona falcata*. The species diversity of Lake Arkto-Pimberto is determined mostly by northern species. The dominant position of littoral taxa indicates the prevalence of the littoral zone in the lake. The species diversity of cladocerans was low. No significant changes were observed in the development of cladoceran communities. The historical formation of Lake Arkto-Pimberto was uniform in different zones. Based on the Shannon index, the lake is β -mesotrophic. According to the Pantle–Buck index modified by Sladeczek, the lake is oligosaprobic.

The spore-pollen spectrum from the sediments were dominated by arboreal taxa. Pollen of *Betula* sp., Cyperaceae and *Sphagnum* spore were present throughout the core in relatively constant percentages. Four palynological zones are definable under consideration on the basis of the spore-pollen. The spore-pollen spectra from the PZ I are characterized by a prevailing share of arboreal taxa pollen mostly represented by *Betula* spp., *Salix*, *Alnaster* with the presence of heather (Ericaceae) communities. The PZ I was deposited in wetter conditions. The spore-pollen spectra from the middle layers of the core (PZ II PZ III) are characterized by an increased concentration of herbaceous taxa pollen. The pollen spectrum from the PZ IV reflects the development of moss and low-growing shrubs in wet climates.

4. Conclusions

We analyzed the structure of the subfossil cladoceran community, pollen and diatoms in sediments of Lake Arkto-Pimberto in the Pechora River delta. The predominance of pollen of arboreal taxa is a distinctive features of the spore-pollen spectra of lake sediments. The pollen content of non-arboreal taxa is 10-20%. The pollen of *Betula* spp., Cyperaceae and *Sphagnum* spp. has a more or less constant percentage throughout the core. A total of 16 cladoceran taxa were found in sediment core 18-Pe-01C. In general, the crustacean remains were distributed evenly throughout the core. *Bosmina (Eubosmina) longispina*, the cold-water taxon characteristic of oligotrophic water bodies, was absolutely dominant in all stratigraphic zones. Based on the Shannon index, the lake is β -mesotrophic. According to the Pantle–Buck index modified by Sladeczek, the lake is oligosaprobic.

The ecological and geographical analysis of the diatom species composition showed the dominance of Holarctic, benthic, and alkaliphilic species with the abundance growth under moderate temperatures. With the help of the cluster analysis, the entire core was divided into three zones based on the presence of diatom taxa and their relative abundance. The first zone corresponds to the stage when the lake was characterized by the mass development and diversity of diatoms, thereby reflecting the period of the high water level and the formation of a deep and less mineralized water body. Diatoms were present in small number or absolutely absent in the middle layers of the core. In the upper part of the core, there is significant an increase in the number of diatoms.

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Conflict of interest

Authors declare no conflict of interest.

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Short communication

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The dynamics of macrophytes in Lake Vitalievskoye (Valaam Island, Russia) after level changes of Lake Ladoga during the Late Holocene

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ABSTRACT. Aquatic vegetation is a sensitive indicator of lake structural rearrangements, water level changes, overgrowth and waterlogging processes. Although macrophyte pollen may not be well preserved in lake sediments, it is a valuable source of information about an evolution of lakes. Continuing our previous researches on the use of macrophyte pollen analysis in paleolimnological studies, we have explored the sediments sequence of Lake Vitalievskoye on the Valaam Island (northern part of Lake Ladoga), that was isolated at the Ladoga regression for the Late Holocene. We have used pollen analysis of the sediments sequence with focus on the dynamics of aquatic vegetation. Based on our results, the macrophyte dynamics at every stage of the Lake Vitalievskoye development and relationship with the Lake Ladoga level changes in the Late Holocene were reconstructed.

Keywords: Lake Ladoga, Late Holocene, lake sediments, macrophytes, pollen analysis

1. Introduction

Lake Vitalievskoye is located on the Valaam Island (northern part of Lake Ladoga). It is a small lake surrounded by pine forest with spruce and birch with an area of 0.005 km² and a depth of up to 1.9 m. The lake was a part of Lake Ladoga at an early stage of its development and isolated from it in the Late Holocene due to the Ladoga's regression.

This article is a logical continuation of our previous researches of a role of macrophytes pollen in paleolimnological studies (Gazizova et al., 2020; Gazizova and Sapelko, 2020; 2021). There are many studies about aquatic vegetation including paleoenvironmental reconstructions (Taavitsainen et al., 1994; Saarnisto and Vuorela, 1998), however, we tried to explore potential use of macrophyte pollen in the reconstruction of the lake evolutionary history and the lake level changes. The macrophyte pollen in sediment sequences of some other lakes on the Valaam Island have been already studied (Vuorela et al., 2001; Saarnisto, 2012), and we have compared our results with existing data.

2. Materials and methods

Lake Vitalievskoye (10.8 m a.s.l.) were studied during paleolimnological field works of the Institute of

Limnology RAS in summer 2019 and 2021. The lake sediments sequence was taken using a Russian corer (Sapelko et al., 2020). In addition, the modern aquatic vegetation of Lake Vitalievskoye was described and the surface samples of lake sediments were taken using a Voronkov's sampler. Received materials were studied using pollen analysis with focus on the macrophyte pollen.

3. Results and discussion

Based on pollen analysis and the existing studies of level changes of Lake Vitalievskoye (Saarnisto, 2012; Sapelko et al., 2018), we have reconstructed three stages of its Late Holocene development (Fig.). At the first stage (the Late Atlantic – Early Subboreal), Lake Vitalievskoye was part of Lake Ladoga, its poor aquatic vegetation was represented by *Potamogeton* spp. and *Sparganium* spp. At the second stage (end of the Subboreal), the lake was isolated from Lake Ladoga. At the first, the level of Lake Ladoga had decreased and it was a cause of the destabilization of this ecosystem. This process was accompanied by the disappearance of macrophytes pollen from pollen spectra. A similar absence of aquatic vegetation pollen is observed in the sediments sequence of other lakes in the Ladoga region (Delusin and Donner, 1995; Vuorela et al., 2001; Saarnisto, 2012; Sapelko et al., 2014; Gazizova

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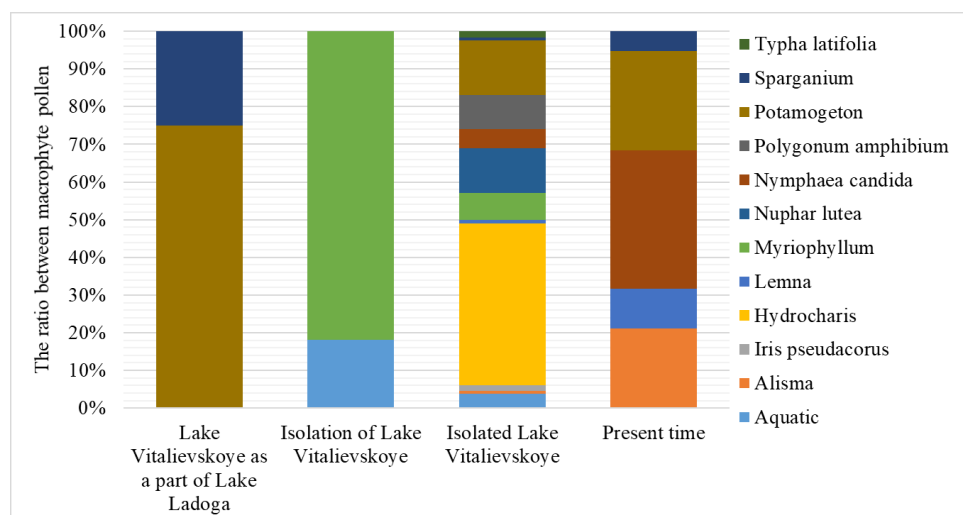


Fig. The representation of macrophytes pollen at the different stages of the Lake Vitalievskoye development.

et al., 2020; Gazizova and Sapelko, 2020; 2021). The following gradual loss of a connection with Lake Ladoga led to formation of the lagoon sedimentation in Lake Vitalievskoye. *Myriophyllum* spp. was the pioneer species for Lake Vitalievskoye aquatic vegetation when the lake ecosystem slow stabilized.

At the third stage (the Subatlantic) Lake Vitalievskoye has finally lost its connection with Lake Ladoga and the isolation process was finished. Fully isolated Lake Vitalievskoye was gradually populated with aquatic vegetation. *Myriophyllum* spp. was the only represented species for a long time, however, *Hydrocharis* spp., *Polygonum amphibium* and *Potamogeton* spp. Also appeared. *Nuphar lutea* latterly spread. The role of *Myriophyllum* spp. reduced and completely disappeared while *N. lutea* was appearance. Then *Nymphaea candida* spread and *Hydrocharis* spp. was a dominant; *N. lutea*, *Potamogeton* spp. and *P. amphibium* were prevailing species, too.

In the present time Lake Vitalievskoye is a small overgrown and overlogged lake with appropriate aquatic vegetation, which is represented by *Alisma* spp., *Lemna* spp., *N. candida*, *Potamogeton* spp. and *Sparganium* spp. according to pollen analysis of the surface samples of lake sediments. Additionally, the field description of modern aquatic vegetation showed the presence of *Hydrocharis morsus-ranae* and *N.lutea*.

4. Conclusions

The macrophyte dynamics at every stage of the Lake Vitalievskoye development was reconstructed. The obtained data helped us to reconstruct the Late Holocene history of the lake and describe its isolation process from Lake Ladoga.

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Conflicts of interest

The authors declare no conflicts of interest.

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Short communication

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Cladocera remains in reconstructions of past ecological conditions of the Yamal Peninsula

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ABSTRACT. The aim of this study is to explore the Cladocera community from the bottom sediments of small unnamed lake (21-Ya-02B) whilst attempt to reconstruct the ecological and climatic conditions for the Yamal Peninsula. In total, remains of 37 taxa were identified in bottom sediments of the lake. Cladocera community in the lower layers at the column is represented by low taxonomic abundance and typical northern species. On the depth of 65-40 cm the maximum number of taxa was identified, which allows it to be considered the temperature optimum zone of Cladocera. Changes in the upper layers of the column may indicate climate warming in the study area and, as a consequence, thawing of permafrost.

Keywords: Cladocera, bottom sediments, Holocene, Yamal Peninsula, thawing of permafrost

1. Introduction

Recent decades have been characterized by noticeable climate change occurring in the Arctic faster and on a larger scale than in the rest of the world (Nigamatzyanova et al., 2021; Fefilova et al., 2022). Warming occurs synchronously for the Western Arctic region with short-term fluctuations, with both increasing and decreasing average annual temperatures observed. Climate warming is accompanied by an increase in annual precipitation (Shirokov and Vasiliev, 2019). Studies of lakes bottom sediments are of particular importance for reconstructing the ecological and climatic conditions of the past, whilst also assessing the current state of lakes (Smol et al., 2005). Algal and invertebrate remains (Chironomidae and Cladocera) are among the most common paleo indicators in lake sediments that provide reliable records of changes in water quality, habitat and catchment processes (Smol et al., 2005; Frolova et al., 2016; Ibragimova et al., 2020). The aim of this study is to explore the Cladocera community from the bottom sediments of small unnamed lake (21-Ya-02B), which is close to Lake Tabortato, whilst attempt to reconstruct the ecological and climatic conditions for the Yamal Peninsula.

2. Materials and methods

The Yamal Peninsula is located above the Arctic Circle, between the Kara Sea to the north and West, Baidaratskaya Bay in the southwest, and Obskaya Bay in the east. The territory is generally flat, hilly in the north, and elevated in the central part, elongated in the meridional direction, with elevations up to 100 m above sea level. The surface is cut in varying degrees by river and ravine network, heavily marshy and waterlogged. The Yamal Peninsula is located in a permafrost zone, a zone of tundra that changes from south to north from a narrow strip of forest tundra to arctic tundra. The climate of the peninsula is harsh, winter lasts 8-9.5 months (Atlas..., 2004). The study lake is located in the southwest of the Yamal peninsula (N 68°09'53.8", E 68°57'36.1"). The lake is round and small, coastal vegetation includes small bushes, moss and grass. The bottom of the lake is muddy. In July 2021, specialists of Kazan Federal University collected a column of bottom sediments of the lake using Gravity corer. The depth of sampling of the bottom sediment column was 4.3 m, the length of the column was 67 cm. For Cladocera analysis, bottom sediment samples were sliced in 1 cm increments. Thus, for Cladocera analysis

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35 samples of the bottom sediments were selected using a method of sample preparation improved by Korhola and Rautio (2001). In each sample 200 specimens were identified at minimum. The maximum number of headshields, carapaces or postabdomens of a single taxon was used to calculate the total number of specimens in the sample. Identification of the Cladocera remains was carried out using an Olympus BX41 (Olympus Corporation, Japan) (magnification x100-400) light microscope along with specialized keys for identification subfossil (Szeroczyńska and Sarmaja-Korjonen, 2007) and modern Cladocera (Kotov et al., 2013). Statistically significant stratigraphic zones were identified using CONISS cluster analysis of the Tilia/TiliaGraph software.

3. Results

In total, remains of 37 taxa belonging to 5 families of Cladocera (Chydoridae, Bosminidae, Daphniidae, Sididae, Macrothricidae) were identified in bottom sediments of the unnamed lake. The species diversity is mainly represented by the remains of the family Chydoridae. According to the stratigraphic diagram of Cladocera taxa distribution in bottom sediments of the studied lake, 4 faunistic zones can be distinguished. In the lower part of the column (Zone I, 70-65 cm) the least number of taxa - 15 taxa - was identified. *Alonella nana* - 34.49 %, *Chydorus* cf. *sphaericus* - 24.45 %, *Eubosmina* (*Bosmina*) cf. *longispina* - 17.35 % are subdominants. Cladocera community in this zone is represented by typical northern species. Zone II (65-40 cm) shows the greatest species diversity, where remains of 32 taxa were identified. The greatest number of remains belongs to *A. nana* - 27.73 %, *C.* cf. *sphaericus* - 26.96 %, *E. (B.)* cf. *longispina* (18.41 %) remains. The increase in taxonomic diversity is due to the development of the littoral complex. In zones I-II the remains of *Sida crystallina*, *Rhynchotalona latens*, *Camptocercus fennicus* are found, which are associated with cold climate and low content of organic matter. In zone III, significant changes in the ratio of identified taxa are observed: the role of dominant in the Cladocera community is played by *E. (B.)* cf. *longispina* (73.87 %). The share of *C.* cf. *sphaericus* (14.83 %), *Acroperus* sp., *Alona guttata tuberculata*/ *Alona rectangula pulchra*, *A. nana* (0.41 %) decreases. In zone IV, a decrease in taxonomic diversity was observed - 18 taxa were identified. The dominance of *E. (B.)* cf. *longispina* (50.3 %) is noted, *C.* cf. *sphaericus* (27.49 %) is subdominant. The proportion of representatives of *Alona* s.lat. increases, while the remains of representatives of the genus *Alonella* are not found in Zone IV.

4. Discussion

Low taxonomic diversity of the lower part of the bottom sediment column is common for lakes of glaciogenic origin (Frolova and Ibragimova, 2015). Zone I is represented by remains of typical northern species associated with low temperatures. There is an increase in taxonomic diversity in the upper layers.

The Cladocera community of this zone indicates the cold climate during this period. The maximum number of remains of *A. nana*, classified as a subarctic taxon, is noted here. However, this species is also strongly associated with vegetation and has a pronounced ecological preference for dystrophic lakes with sphagnum mosses (Fryer, 1968). The presence of higher aquatic vegetation and oligotrophic conditions in the reservoir is indicated by the remains of *S. crystallina* (Flössner, 2000). The maximum number of taxa was identified in zone II, which allows it to be considered the temperature optimum zone of Cladocera, although the remains of northern species (*C. fennicus*, *R. latens*, *A. harpae*, *A. nana*) testify to low temperatures in the study region. The increase in taxonomic diversity is due to the appearance of taxa inhabiting overgrown areas of water bodies. In zone III the dominant communities change, a significant increase in the proportion of pelagic *E. (B.)* cf. *longispina* may indicate a change in temperature regime in the study area and, as a consequence, thawing of permafrost. There is a decrease in the proportion of littoral species and species associated with vegetation. Northern species reduce their abundance in favor of warm-water forms: *C. fennicus* is replaced by *C. rectirostris*. In zone IV, taxonomic diversity continues to decrease, indicating changing conditions in the watershed and in the lake. The increase in the proportion of *C.* cf. *sphaericus* at the present stage of the lakes is often associated with eutrophication (Flössner, 2000), as well as with the release of organic matter during permafrost thawing. The increase in the proportion of *B. longirostris* in the surface sediments is also classified as a sign of an increase in the trophic status of the lake. Similarly, to those observed in previous investigations in other tundra lakes within Russia (Frolova and Ibragimova, 2015; Frolova et al., 2016; Ibragimova et al., 2020).

5. Conclusions

Significant changes in subfossil Cladocera community of the studied unnamed lake on the Yamal Peninsula are noted from a depth of 40 cm of the bottom sediments: there is a change in the dominant complex, an increase in the proportion of pelagic taxa and taxa associated with eutrophication. The above may be a consequence of climate change and thawing of permafrost in the study area.

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Conflict of interest

The authors declare no conflict of interest.

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Lithochemical parameters in equilibrium systems of modern sedimentation in lakes and on the sea shelf

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ABSTRACT. The work combines physicochemical and statistical modeling in the description of marine and continental salt water bodies. Sedimentary systems consist of aluminosilicate, carbonate and organogenic source material. Paleoclimatic changes are traditionally considered in the time scale. However, the real fluctuation amplitude of the target natural parameter is usually absent or has insufficient resolution for quantitative paleoclimatic reconstructions. Accessible quantitative analysis of time series is based on mineralogy and geochemistry of bottom sediments. Analytical complex includes X-ray phase diagnostics of minerals, SEM and XRF analysis of bulk chemical composition, isotopic dating and counting of annual rhythms. Modern high-resolution technique like scanning XRF SR with a measurement step of 1 mm successfully provides the necessary synchronization between analytical data and instrumental seasonal-annual observations. Multiple regression methods are used to calculate the transfer functions for transforming the elemental composition of sediments into time series of the desired target environment. Additional physicochemical equilibrium estimates of sedimentation were calculated, confirming the convergence of the parameters of the selected multisystem (rock + liquid + gas) with environmental conditions. For equilibrium systems, time series of absolute values of the desired parameters, such as temperature, salinity, pH, redox environment, etc., were calibrated with synchronous weather and climate fluctuations. In particular, the reconstruction of marine sediments opened up the prospect of studying the periodicity of ice-free periods in the Arctic Ocean, using quantitative estimates of external conditions from the lithochemistry of bottom sediments.

Keywords: sedimentation, paleoclimate, time series, physicochemical modeling

1. Introduction

The work combines physicochemical and statistical modeling in the description of marine and continental salt water bodies. Sedimentary systems consist of aluminosilicate, carbonate and organogenic source material. Paleoclimatic changes are traditionally tied to a time scale. However, the real fluctuation amplitude of the target natural parameter is usually absent, or has insufficient resolution for quantitative paleoclimatic reconstructions. Purposeful detailed sampling and quantitative analysis of time series are preferable. In accordance with the source of material and the predominant mechanism of accumulation, in the general case, three lithochemical proxy groups are distinguished: 1) clastogenic with the participation of Rb, Sr, Zr, density (clays and other

slightly weathered mineral particles), 2) chemogenic - Ca, Mg, Sr carbonates and organic redox products, and 3) degrading organic masses with a wide range of water-soluble material. Currently, we are considering climate-dependent parameters in reactive clastogenic-biogenic-chemogenic systems, based on the fact that the identified geochemical signals of bottom sediments reflect changes in the area of interest. These are, for example, the components Br, Mo/Mn, Rb/Sr, Sr, Ca/Sr, Co-Inco, etc. known in the literature, and calibrated by the synchronous series of hydrometeorological observations. For the analysis of the paleoenvironment, Lake Van, located in the semiarid zone of the continental climate, as well as shallow-water (shelf) deposits in the Siberian Arctic (Chukchi Sea) were selected. A comparative study of lacustrine and marine sedimentation makes it possible already at the

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first stage to calculate the parameters of equilibrium mineral formation and evaluate the correctness of reconstructions by the physicochemical approach. Experience shows that the more features, the better the correlation between proxy and instrumental weather data on the transfer function calibration interval.

2. Materials and methods

X-ray phase diagnostics of minerals, SEM and XRF analysis of bulk chemical composition, isotopic dating and counting of annual rhythms. High-resolution geochemical analysis (scanning XRF SR with a measurement step of 0.5 mm) fully provides the necessary synchronization between analytical data and instrumental seasonal-annual observations. Multiple regression methods were used to calculate the transfer functions for transforming the elemental composition of sediments into time series of the desired target environmental parameters. The primary minerals of the deposits and the bulk chemical composition of the basin water are given in tables 1 and 2. Table 1 was used as initial information in the simulation, and Table 2 served to check the specified ratios of the main proxies.

The sediments of the lake Van has a large content of carbonates ($\text{CaO} \sim 20\%$), and on the Arctic shelf - silty clays ($\text{SiO}_2 \sim 60\%$, $\text{CaO} < 2\%$). The modern salinity of Lake Van is 22 g/l, and the Ca/Sr value ranges from 70 to 170 (average 123), while in shelf sediments the ratio ranges from 14 to 31 (average 24, see Table 3).

Based on the mineralogical and bulk chemical analysis of the reservoirs, physicochemical equilibrium estimates of sedimentation were calculated, confirming the convergence of the parameters of the selected multisystem (rock + liquid + gas) with environmental conditions.

3. Results

In addition to the well-known geochemical features, Ca/Sr is considered as a permanent salinity index of basin and pore water, which are controlled by climatic factors and are modeled by the water/rock ratio in the calculated diagrams (Tret'yakov et al., 2012). In a setting of stable water balance of lakes, the value of Ca/Sr in the sediment is inversely proportional to the salinity of the basin and pore water. For example, the maximum freshening in Lake Van over the past millennium is associated with a sharp rise in Ca/Sr during the period of massive melt water inflow immediately after the Maunder minimum.

Strontium is fixed in the sediment as an isomorphic admixture of strontianite in biogenic aragonite due to

Table 1. Mineral composition of lacustrine (Lake Van) and marine sediments (shelf of Chukchi Sea).

Van Lake sample 2015– 3, age 1090 – 1100 yrs BP	Smectite and illite-smectite $\sim 40\text{--}50\%$, muscovite type mica $\sim 10\text{--}15\%$, chlorite $\sim 5\%$, calcite $< 5\%$, aragonite $< 5\%$, NaCl $< 5\%$, quartz $< 5\%$, kaolinite $< 5\%$, dolomite $< 5\%$, monohydrocalcite $< 5\%$, possibly thenardite
Chukchi Sea, Station B 7, age 220– 230 yrs BP	Muscovite type mica $\sim 25\text{--}30\%$, quartz $\sim 25\text{--}30\%$, plagioclase and Kfs $\sim 10\text{--}20\%$, Fe-Mg chlorite $\sim 5\text{--}15\%$, NaCl $< 5\%$, monohydrocalcite $< 5\%$, hematite or pyrite $< 5\%$, amphibole $< 5\%$, illite-smectite $< 5\%$

the similar crystallographic lattice in these carbonates. The Gibbs free energies of the formation of carbonates without Mg differ insignificantly. So calculating the equilibrium reveals aragonite and monohydrocalcite are released only when the formation of calcite is suppressed (calculation of quasi-equilibria).

Using the “Khch” program, Moscow State University, (Shvarov, 2008) the equilibrium of Lake Van and the shelf of the Chukchi Sea with brine and sea water, respectively, was calculated. Thermodynamic calculations were carried out in a heterophase 18-component system H-O-C-Cl-N-S-P-Al-Si-Na-K-Ca-Mg-Mn-Fe-Ba-Sr-Br at 10°C and a total pressure of 1 atm according to the KhCh program as well as to the GIBBS algorithm and the UNITERM thermodynamic database. When calculating water-rock, 100 g of the solid phase was taken.

4. Discussion and conclusions

Table 3 shows the results of calculations of the solid phase, where minerals content is normalised to 100%). After interaction water/rock in an acid-base environment (pH), the calculated result corresponds to the values measured in situ. This makes it possible to predict a decrease in the concentration of both calcium and strontium in solution due to an increase in the stability of $(\text{Ca,Sr})\text{CO}_3(\text{s})$ solid solutions. At the same time, there is also a change in the types of both soluble Ca and Sr. If Ca^{2+} and Sr^{2+} prevail in sea water and the proportion of sulfate complexes is 13 and 17%, respectively, then in lake water Na-HCO_3^- Type SO_4 carbonate complexes in the form of MeCO_3 and MeHCO_3^+ play a significant role up to 60 and 44%,

Table 2. Chemical composition of sediments, %wt.

Basin	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	Ca/Sr	LOI	Sum
Van Lake	26,86	0,27	5,46	2,95	0,09	9,18	19,55	2,99	0,41	0,19	2,21	123	28,02	98,18
Chukchi Sea	59,33	0,68	12,3	5,64	0,05	2,54	1,7	3,72	2,36	0,19	0,38	24	10,41	99,3

Table 3. Mineral composition model of the bottom sediments of the Chukchi Sea and Lake Van after interaction of 100 g solid and 1 kg of solution at 10°C, Eh 0.3V, pCO₂ 10-3.5 atm. Calculated pH and species of calcium and strontium in solutions are shown (%).

Mineral	Chukchi Sea,%	Van Lake,%	Parameter	Chukchi Sea,%	Van Lake,%
Quartz	25,67	26,28	pH _{calc.}	8,4	9,8
Hematite	9,06	0,00	Ca ²⁺	85,00	35,72
Calcite	7,67	17,02	CaCO ₃ ⁰	0,89	60,45
Strontianite	0,04	0,04	CaSO ₄ ⁰	13,22	3,83
Muscovite	29,19	32,45	CaCl ⁺	0,01	no
Chlorite	16,65	9,06	Sr ²⁺	77,11	48,16
Kaolinite	no	15,15	SrCO ₃ ⁰	0,60	44,34
Albite	7,38	no	SrSO ₄ ⁰	17,39	7,50
Microcline	4,34	no	SrCl ⁺	4,31	no
			Ca/Sr	14-31	70-170

respectively. When we simulated equilibrium at a water/rock ratio of 10, that is, these are the first stages of interaction, marked by intense chloritization (Chukchi Sea, 16.65%) or kaolinization (Van, 15.15%). The nonequilibrium of waters with clastic aluminosilicates (plagioclase, amphibole, etc.) has a complex chemical nature associated with the influence of hydrolysis products on various subsequent chemical processes.

Nevertheless, a stationary, equilibrium-nonequilibrium system develops everywhere. With a decrease in the water/rock ratio by a factor of 100, stable smectites and illite-smectites (pore aquatic environment) are already observed. Under these conditions, the Van Lake deposits are more mature, and accompanied by a high proportion of organic and clay components and a higher Ca/Sr ratio as well. The presence of pyrite in the sediments of the Chukchi Sea indicates reducing conditions and the activity of sulfate-reducing microorganisms. Under model conditions, they correspond to the value Eh -0.3 V.

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Conflict of interest

The authors declare no conflict of interest.

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Chlorophenolic compounds in bottom sediments of the boreal lake as a specific mark of anthropogenic impact

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ABSTRACT. The paper presents the results of multi-year studies of bottom sediments of a boreal lake (the south-west of the Arkhangelsk region, Russian Federation), which exist under a specific anthropogenic impact, namely, the long-term usage of a chlorophenol-containing biocide (NaPCP) in the past. It is shown that levels of pentachlorophenol (PCP) significantly decreased after more than two decades since the discontinuation of biocide usage. However, an increase in levels of PCP derivatives (namely, toxic chlorinated guaiacols and catechols) in lake sediments was found. These chlorophenolic compounds were detected in a state inaccessible for biodegradation, which indicates their persistence in sediments for a long time.

Keywords: chlorophenolic compounds, chlorophenolic-containing biocide, bottom sediments, boreal lake

1. Introduction

In the northern regions of Russia for a long time, until the 1990s, the chlorophenol-containing biocide (NaPCP) was intensively used for timber treatment, which led to soil contamination at the industrial sites of timber mills with residual amounts of biocide components (Kolpakova and Velyamidova, 2019). Its main component was pentachlorophenol (PCP). Due to its high toxicity, ability to transboundary transfer, accumulation in the environmental compartments and bioaccumulation in higher trophic levels, PCP was included in the list of persistent organic pollutants (POPs), which are the subject to the complete elimination of production and use in accordance with the Stockholm Convention on Persistent Organic Pollutants (May 17, 2004). The study of the distribution, "fate" and transformation of POPs in natural ecosystems refers to a set of practical measures aimed at reducing its negative impact on the environment and public health. Over time, PCP can be converted in environmental media to other organochlorine compounds, in particular chlorophenolic compounds (Field and Sierra-Alvarez, 2007). At the same time, the toxicity of some chlorine derivatives exceeds the toxicity of PCP itself (Field and Sierra-Alvarez, 2007).

This paper presents the results of multi-year monitoring studies of the bottom sediments of a small shallow boreal lake (in the south-west of the Arkhangelsk region, RF), located near the industrial site

of the shutdown timber mill and the timber treatment site itself.

2. Materials and methods

Sampling and analysis of bottom sediments were carried out by employees of the Laboratory of Eco-Analytical Research of the N. Laverov Federal Center for Integrated Arctic Research (Arkhangelsk). The detailed description of the object of studies and the analytical procedure were presented in Kolpakova and Velyamidova (2019).

3. Results and discussion

Reconnaissance studies of the bottom sediments of a small shallow boreal lake in the south-west of the Arkhangelsk region were carried out in 2002, 7 years after the timber treatment was discontinued. Pentachlorophenol has been detected in lake sediments at concentrations from 22 to 30 ng g⁻¹ (Kolpakova and Velyamidova, 2019). To obtain information on trends in the behavior of residual toxic organochlorine components of the biocide, studies were continued in 2012 and 2017. A decade after this reconnaissance studies, content of PCP in lake sediments increased up to 189 ng g⁻¹, exceeding the predicted no effect concentration of this pollutant in sediments (124 ng g⁻¹) (Toxicological profile..., 2001). According to the results

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of studies in 2017, contents of PCP in lake sediments have noticeably decreased (to 1-8 ng g⁻¹).

As is known, bottom sediments of small shallow low-flow lakes are considered effective “traps” for bioaccumulative toxic organochlorine components of biocide (including PCP), the accumulation of which in silty sediments with a high content of organic matter was especially significant during the period of intensive NaPCP usage (Kolpakova, 2018). One of the reasons for the decrease in the levels of these pollutants in sediments during the observation period is most likely the decrease of their soil “residues” in the drainage area of the studied lake as the result of more intensive organochlorines transfer into the aquatic environment in previous years. In addition, the residual amounts of the organochlorine components of biocide associated with the organo-mineral matter of soils are less mobile to date (Kolpakova and Velyamidova, 2019).

On the other hand, the behavior of ionogenic PCP (including migratory mobility) strongly depends on the physicochemical properties of the environmental media itself, and, first of all, on the pH value (Toxicological profile..., 2001). It has been established that over the past decade there has been no significant change in the pH values of lake sediments: pH 6.60-7.03. At these pH values, PCP was present in sediments mainly in the ionized form (more mobile and water-soluble form, with a low ability to be sorbed in silty sediments), which favored intensive transfer of this pollutant in the aquatic environment and participation in degradation/transformation reactions (Lyytikainen, 2001).

The most effective mechanism of PCP degradation is considered to be the microbial degradation/transformation with the formation of its derivatives (Field and Sierra-Alvarez, 2007) under various conditions of the aquatic environment. At the same time, it is known that, depending on the pH, both bioavailable and non-bioavailable PCP forms (easy and hard to extract fractions, respectively) with different degrees of sorption on soil particles are formed (Lyytikainen, 2001). Earlier, in 2002 and 2012, PCP was found mainly in the easy to extract fraction, which contributed to its active involvement in the microbial degradation/transformation with the formation of other chlorophenolic compounds with varying toxicity and lipophilicity. In 2017, PCP was found in sediments in both easy and hard to extract fractions.

Another significant factor is the content of organic carbon (C_{org}). In 2012 and 2017, C_{org} in lake sediments was determined in large amounts – from 11.19 to 30.89%. According to some researches (Field and Sierra-Alvarez, 2007; Gaofeng, 2004), the rate of PCP transformation increases in bottom sediments and soils with a high C_{org} content. However, when interacting with soil organic matter, PCP is able to form various more persistent compounds, diffusing into soil aggregates, elementary soil particles, thus becoming less bioavailable (Lyytikainen, 2001).

In 2012, the composition of chlorophenolic compounds in the bottom sediments of the anthropogenically loaded lake reflected the profile of the compounds found in the soils of the adjacent

industrial site of the timber mill. PCP (46-189 ng g⁻¹), 3,4,5-trichloroguaiacol (15-150 ng g⁻¹), and 4,5,6-trichloroguaiacol (up to 13 ng g⁻¹) accounted for 60-70% of the total content of chlorophenolic compounds in lake sediments. Also, 2,4,5-trichlorophenol was found in lower concentrations (1-8 ng g⁻¹). Other high-chlorinated compounds (2,4,6- and 2,3,4-trichlorophenols, 2,3,5,6-tetrachlorophenol) were found less frequently and in very small concentrations, less than 3 ng g⁻¹. Low-chlorinated compounds were mainly represented by 4-chlorophenol (34-69 ng g⁻¹) and 2,6-dichlorophenol (16-17 ng g⁻¹).

After 15 years from the date of reconnaissance studies, the content of chlorophenolic compounds in recent lake sediments has increased significantly. Thus, once in 2012 concentrations of chlorophenolic compounds were 80-337 ng g⁻¹, then in 2017 they were already 700-3146 ng g⁻¹. At the same time, low-chlorinated compounds already dominated in the chlorophenolic composition (from 59 to 77%), while in 2012 high-chlorinated compounds still prevailed (from 64 to 100%).

Moreover, the concentrations of the dominant toxic PCP and trichloroguaiacols decreased over time by an order of magnitude (to 2-8 ng g⁻¹). Such a strong decrease in their concentrations was apparently associated with the active reductive dechlorination under the influence of anaerobic microorganisms, the products of which are low-chlorinated compounds. Indeed, the concentrations of mono- and dichlorinated compounds were by orders of magnitude higher than the concentrations of PCP, tetra- and trichlorophenols and their derivatives.

In 2017, low-chlorinated phenols were determined in the lake sediments in the greatest amounts: 2-chlorophenol (71-535 ng g⁻¹g), 4-chlorophenol (96-188 ng g⁻¹), 2,4-dichlorophenol (76-329 ng g⁻¹), 2,6-dichlorophenol (14-124 ng g⁻¹), and 2,4,5-trichlorophenol (31-788 ng g⁻¹).

Such toxic derivatives of chlorophenolic compounds as hydroxychlorophenols (chlorocatechols) were found in recent lake sediments in concentrations of the same order. 3,4-, 3,5- and 4,5-dichlorocatechols, as well as 3,4,5-trichlorocatechol and tetrachlorocatechol were identified. The chlorocatechols contribution ranged from 24 to 50% in the total content of chlorophenolic compounds. The presence of chlorocatechols in lake sediments was possibly associated with both the supply of these compounds from the soils of adjacent territories and their formation as the result of aerobic microbial transformation of chlorophenols (mainly in the soils of adjacent territories).

4. Conclusions

Thus, 22 years after the timber treatment was discontinued on the timber mill, the concentrations of PCP as the main component of chlorophenol-containing biocide (NaPCP) in lake sediments have significantly decreased. The composition of chlorophenolic compounds in recent lake sediments

was mainly represented by toxic chlorophenols and chlorocatechols. The presence of chlorinated derivatives of PCP in a state difficult for biodegradation and their amounts suggest that the compounds remain in bottom sediments for an indefinitely long time. The obtained data on the content of PCP and other chlorophenolic compounds can be used to assess the current state of the studied lake and other similar aquatic ecosystems in the Arkhangelsk region in terms of contamination with persistent toxic organochlorine components of biocide because of its long-term usage in the past.

Conflict of interest

The authors declare no conflict of interest.

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New data on the rise of Lake Ilmen (NW, Russia) in the Holocene

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ABSTRACT. This paper discusses a rise of Lake Ilmen in the Holocene, its origin, and consequences for the Neolithic culture of the region. We assume that in the second half of the Holocene there was a long-lasting level rise of Lake Ilmen. The level rise was associated with the Holocene Ladoga transgression into the Ilmen-Volkhov basin.

Keywords: Lake Ilmen, Ilmen-Volkhov river basin, Neolithic man sites on the Northern Ilmen lakeside, Ladoga transgression, Kolomtsy

1. Introduction

The Kolomtsy is the best known site in the Northern Ilmen lakeside (Borisevich, 2022). The Kolomtsy Neolithic site on the northern Ilmen lakeside was firstly discovered in 1888 by amateur archaeologist V.S. Peredolsky on the right bank of the Volkhov River (Peredolsky, 1898). According to V.S. Peredolsky (1893), it is known that the cultural layer of the site was buried under a layer of ‘brick-colored sandy clay’, which had the same and significant thickness of 1.3–1.5 m all over the site. In 1893, the Imperial Archaeological Commission sent geologist A.A. Inostrantsev to revise the methodology of previous excavations. A.A. Inostrantsev compiled a detailed report about a local stratigraphy and pointed special attention to the red clay layer (Inostrantsev, 1905). Opinions of V.S. Peredolsky and A.A. Inostrantsev about a lifestyle of ancient Kolomtsy were differ. Thus, V.S. Peredolsky assumed that people dwelled there permanently and locally shifted a settlement when a level of Lake Ilmen was high due to heavy rainfalls and flooded the site (Peredolsky, 1893). However, A.A. Inostrantsev convinced that a lifestyle was a semi-nomadic and settlement on lakesides was seasonal when the water level dropped after spring floods. It was confirmed by thin layers of organic debris inside the bed of washed sand (Inostrantsev, 1905).

In 1901, V.V. Peredolsky unearthed a site located three kilometers south of the Kolomtsy. He wrote that “at a depth of 1–7 sazhen (~2–14 m), alluvial deposits was changed by red sandy clay which is as thick as 1 sazhen (2.13 m)” (Peredolsky, 1906).

In the 1920s, geomorphologist N.N. Sokolov (Malakhovsky et al., 1960) who participated in surveying the Ilmen-Volkhov basin before construction of the Volkhov hydropower plant, dug pits at the Kolomtsy site. The pits showed that layers brown clay (1 m) and loam (0.4 m) covered a cultural layer, and these layers were attributed to ‘lacustrine alluvium’ (Sokolov, 1926).

V.S. Peredolsky and V.V. Peredolsky collected and described more than 60,000 artefacts from the both sites (Peredolsky, 1898). Most artefacts were lost during the World War II, but the survived artefacts have great value for researchers. These artefacts were dated the IV–III millennia B.C. (Kashina, 2006; Zhulnikov and Kashina, 2010), and it is obvious that the covering clay layer are the younger than this cultural layer.

The new data is a significant value and they inspire revision and clarification of archival materials unstudied after excavations by V.S. Peredolsky, V.V. Peredolsky and geological survey by N.N. Sokolov.

2. Materials and methods

The Peredolsky’s records indicated that the cultural layer of the site was buried under a 1.3–1.5 m-thick clay layer. To understand this event, many archival materials and publications were studied in addition to fieldworks. Prior to the field studies, the available historical data on the topic were studied using historiographic and problem-chronological methods.

During field works of 2021, we sampled clays from 70-cm-deep pits in various locations within the

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Kolomtsy site. The sampling points were located as follows (Fig.):

- s.p. 1. The Skovorodka hillock (the highest point of the Kolomtsy site);
- s.p. 4. Foot of the Skovorodka hillock;
- s.p. 8. Inferred place of V.S. Peredolsky's excavations;
- s.p. 9. The Ilmen lakeside. Finding of artefactual remains;
- s.p.10 and 11. The Ilmen lakeside at the Volkhov river outflow. Sample 10 was taken at a depth of 10 cm; sample 11, at a depth of 70 cm.

Visually, the clay deposits look identical. To determine their mineral assemblage in the Laboratory of Soil Science and Technical Soil Reclamation of the Lomonosov State University, Moscow, they were subjected to a XRD analysis.

3. Results

Results of XRD analyses indicated that the clays of the Kolomtsy site are almost identical in mineral assemblage (Table). Quartz varies widely (from 17.2% to 36.2%), and it seems to be associated with an irregular supply of a clastic material to the site. Content of smectite also widely changed, it which may indicate a warm condition during certain periods of the studied record.

4. Discussion and conclusions

The data of previous researchers and our studies show that the Neolithic culture layers were overlapped flooding sediment layer in 1.5-m thickness. We adhere with hypothesis that the superficial sediments deposited

Table. Minerals in clays from the Kolomtsy site, %

	1	8	9	10	11	4
Quartz	17.2	36.2	20.8	35	25.5	35.9
Plagioclase (albite)	6.9	8.8	6.5	6.9	6.7	8.8
K-feldspar (microcline)	11.1	10.8	7.8	10.5	9.7	12.2
Cristobalite	<0.5	-	-	<0.5	<0.5	-
Hematite	<0.5	-	<0.5	<0.5	<0.5	<0.5
Ankerite	<0.5	0.6	<0.5	<0.5	-	<0.5
Pyrite	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Kaolinite	6.9	5.7	5.7	6.7	6.6	4.3
Illite	16.6	13.5	12.6	13.9	14.9	12.5
Chlorite	7.3	2.1	4.7	1.1	2.5	2.5
Smectite + Mixed-layer mineral of illite-smectite type	33.1	22.1	41.6	25.1	33.6	22.8

during the maximum of Ladoga transgression, and raising of e Lake Ilmen was depended from it (Borisevich and Komagorova, 2021).

However, there is a conflicting opinion regarding to the impact of the Ladoga transgression on the Lake Ilmen from “it did not affect at all” (Gerasimov and Subetto, 2009) to “the Lake Ilmen level was 7–12 m higher then the modern” (Vasilyeva et al., 2012). We think that convincing relationship of the Ilmen-Volkhov basin history with the history of Lake Ladoga and the Baltic Sea was described by N.V. Vasilyeva et al. (2012) who also mentioned the Kolomtsy site (with reference to V.S. Peredolsky and N.N. Sokolov).

Further studies of the described deposits, as well as the dating of sites with the use of advanced methods, would make it possible to establish whether the flooding of the site was associated with the Ladoga transgression in the Holocene.



Fig. Kolomtsy site sampling points in 2021.

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Conflict of interest

The authors declare no conflict of interest.

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Keywords: ostracods, lake ecosystem, Holocene

3. Results and discussion

Ostracods were found in all samples from the Sargul_pit_2015 section together with shells of gastropod and bivalve mollusks and oogonia of Chara green algae. In addition, single shells of foraminifers were found in 5 samples (Fig. 2). The ostracod fauna is presented by 39 species belonging to 21 genera. The dominated species is *Cyprideis torosa* (Jones). The most diverse and abundant complexes are in the interval of 0-190 cm, below the diversity and abundance significantly reduce almost to extinction, and ostracods reappear at a depth of 297-300 cm. We recognize two ostracod zones in the section. The lower Zone I (before ca. 8 ka BP) shows changeable hydrodynamic and temperature

The Lake Sargul basin includes older lake terrace and the body of the modern lake (Krivonogov et al., 2018). The terrace sediments were investigated in the 150 cm deep pit continued by borehole to the depth of 300 cm, site Sargul_pit_2015 (N 54.58724°, E 78.92059°), in 2015 (Krivonogov et al., 2018). The lake sediments were investigated in the 336 cm long borehole, site Sargul_BH-2019 (N 54.592889°, E 78.873833°), in 2019 (Fig. 1). Both sites were sampled for microfaunal analysis with the interval of 10 cm, totally 56 samples. The analysis was performed with a standard technique. Radiocarbon dates were obtained from shells of mollusks, which are abundant in the sediments.



Fig.1. Map of the Sargul Lake and sites.

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regimes of the lake, which is indicated by episodic occurrence of *Fabaeformiscandona rawsoni* (Tressler), the rheophilic species also used as an indicator of warm-to-cool temperature transition (Fuhrmann, 2012). The upper Zone II (8-4 ka BP) shows regular changes of hydrodynamics, temperature and salinity in the lake; the general trend - increased mineralization, which was favorable for the development of ostracod fauna.

The 260 cm long lacustrine part of the Sargul_BH-2019 core contains ostracods in all samples. Besides, there are shells of gastropod and bivalve mollusks, oogonia of *Chara*, and single shells of foraminifers in

2 samples (Fig. 2). The ostracod fauna is presented by 26 species belonging to 15 genera. *Cyprideis torosa* (Jones) is the dominant species as well. The ostracod complexes are diverse and abundant in the 0-180 cm interval and sharply deplete below. The data shows two ostracod zones. Zone I (ca. 9-4.3 ka BP) represents changeable hydrodynamic and temperature regimes of the lake, but generally the lake water was warm and mineralized. Zone II (4.3-0 ka BP) reflects fluctuating lake level and salinity, and the water was oxygen-saturated. Generally, the lake was more stagnant, less mineralized and colder in this zone.

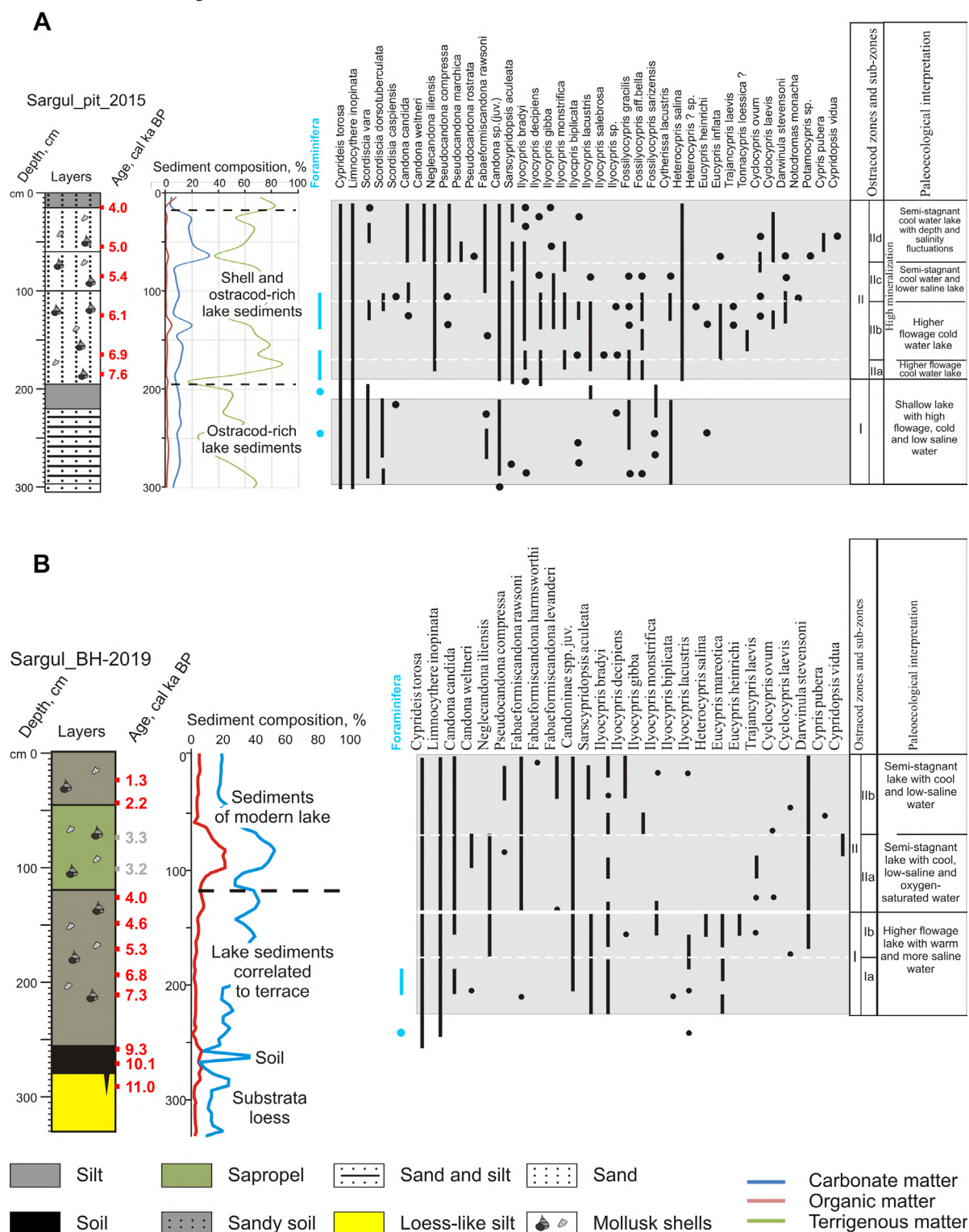


Fig.2. Distribution of ostracods and paleoecological interpretation for the sections Sargul_pit_2015 (A) and Sargul_BH-2019 (B).

These two sites are well correlative by the ecological characteristics of the ostracod complexes. Thus, maximal mineralization falls to the intervals of 230-140 and 190-110 cm in the Sargul_BH-2019 and Sargul_pit_2015, respectively, i.e., to the time periods of 8-4.3 and 8-5.7 ka BP, respectively. The water temperature below 15°C was inherent to 190-10 cm (from 7.6 to 4.0 ka BP) interval in Sargul_pit_2015 and 140-0 cm (from ca. 4.3 ka BP) in Sargul_BH-2019, i.e., this temperature was typical for the whole 7.6-0 ka BP interval. Short events of warmer water environment probably occurred around 5.7 and 2.6ka BP. The lake level lowered 5.1-4.7 and 3.5-2.7 ka BP. A content of rheophylic components of the ostracod complexes decreased since 5.7 ka BP and increased again since 2.7 ka BP.

4. Conclusions

Lake Sargul appeared ca. 9 ka BP and developed in two stages. In the early stage (9-4 ka BP) the lake was larger in area and intensively eroded the shores to form the sandy lake terrace (Krivonogov et al., 2018). It was shallower prior to 7.6 ka BP with water salinity 5-10‰ and water temperature 10-16°C, and deeper 7.6-4 ka BP with increased mineralization and water flow. The water temperature may decrease around 7.3 and 5.3-4.3 ka BP. The salinity and temperature of the water decreased, and the water in the lake became more saturated with oxygen after 4.3 ka BP. The lake level dropped and the water temperature increased 3.3-2.2 ka BP. Later, the lake had low level of water transit, the water salinity fluctuated, and the water oxygen saturation remained high.

Our research confirmed the presence of foraminifera in the lower part of the Lake Sargul section in the period of ca. 9-5.5 ka BP, when the ostracod fauna shows spread of distinctly halobiontic species.

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Conflict of interest

The authors declare no conflict of interest.

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History of the Belye Lakes (the Tsars' valley, Tuva Republic, Russia) in the Late Pleistocene and Holocene

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ABSTRACT. According to the study of bottom sediments, the Belye Lakes (near the famous mound Arzhaan-2) begun to exist about 16.5 ka. The lakes formed in a local depression at the site of the alluvial fans of temporary rivers, which is marked by red sands in cores. A three-meter lacustrine stratum overlies the sands, in some places with interbeds of peat, with a variable content of organic matter and carbonates along the section. Lithological, diatom and pollen analyzes show that the lake has always been shallow. The minimum flowability of the lake, indicating drier conditions, existed 10.0-4.2 ka and for the last 2.0 ka. During the middle of the Holocene (between 8.3-4.2 ka) it could dry up temporarily.

Keywords: sedimentary paleoarchives, climate change, Holocene, pollen analysis, diatom analysis

1. Introduction

There is a 2.5-2.8 ka large complex of Scythian burial mounds known as the "Tsars' Valley" in the Turan-Uyuk basin. In the northern part of the basin there are two groups of lakes located in the closed and semi-closed depressions: the Belye Lakes and the Kislye Lakes. In the south part of basin the Uyuk River is located. One of the burial mounds, Arzhaan-2, is located about 1 km northwest of the Belye Lakes. Previous studies of the sediments of the Belye Lakes were carried out by Dirksen and Chugunov (2007), however, the coastal core was probably not complete. The aim of the study was to reconstruct the conditions of sedimentation and development of landscapes in the Turano-Uyuk basin in the Holocene by study of the deposits of the Belye Lakes.

2. Materials and methods

The core BEL-20-4 was obtained from the central part of the northern waters of the Belye Lakes by Livingstone piston sampler. Total length of the core is 340 cm. The content of organic matter and carbonates in the bottom sediment was determined by loss on ignition. The grain size analysis was performed by the laser diffractometry method. The magnetic susceptibility was measured by ZH Instruments SM 150L at a magnetic field strength of 320 A/m and with a low frequency of 500 Hz. The radiocarbon age of 10 samples was prepared at the Laboratory of Radiocarbon

Dating and Electronic Microscopy, Institute of Geography RAS and measured at the Center for Applied Isotope Studies, University of Georgia (USA). The age-depth model was constructed by Bacon software in R (Blaauw and Christen, 2011). Diatom analysis was performed to reconstruct the ecological characteristics of the lake. Pollen analysis and analysis of non-pollen palynomorphs (NPP) were performed to reconstruct the climatic changes in the Tsars' Valley.

3. Results

Seven layers were identified in the BEL-20-4 core based on the lithological description and variations in analytical characteristics.

Layer 1 (3.40 - 3.15 m, formed until 16.5 ka). The content of organic matter varies from 1.0 to 1.6%, the content of carbonates is about 6 - 7%, the content of terrigenous deposits is about 91-93%. Sand dominates (33-66%), silt varies from 23 to 48%, clay varies from 11 to 19%. Values of magnetic susceptibility are high ($0.45-0.85 \cdot 10^{-6} \text{ m}^3/\text{kg}$). No diatom valves were found in this layer.

Layer 2 (3.15 - 2.50 m, 16.5-12.0 ka). The content of organic matter varies is about 2 - 4 %, the content of carbonates varies from 6 to 11%, the content of terrigenous deposits varies from 86 to 90 %. Silt dominates (52-73%), clay varies from 21 to 30 %, sand varies from 8 to 26%. Values of magnetic susceptibility are very high ($0.2-1.00 \cdot 10^{-6} \text{ m}^3/\text{kg}$). The content of

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benthic diatoms is about 90%, the content of periphytic and planktonic diatoms is a few percent.

Layer 3 (2.50 - 2.30 m, 12.0-10.0 ka). The content of organic matter is 9%, the content of carbonates is 28%, the content of terrigenous deposits is 63%. Silt is 69%, clay is 28%, sand is 4%. Values of magnetic susceptibility are average ($0.18-0.20 \cdot 10^{-6} \text{ m}^3/\text{kg}$). No diatom valves were found in this layer.

Layer 4 (2.30 - 2.10 m, 10.0-8.3 ka). The content of organic matter varies from 9 to 22%, the content of carbonates varies from 57 to 64%, the content of terrigenous deposits varies from 20 to 34%. Silt predominates, its content varies from 64 to 74%, clay varies from 16 to 29%, sand varies from 7 to 19%. Values of magnetic susceptibility are extremely low ($0.0-0.02 \cdot 10^{-6} \text{ m}^3/\text{kg}$). The benthic diatom species (about 54%) dominate in the diatom assemblage. The content of periphytic species is slightly more than 30%, planktonic species content is about 10%. Slightly more than half of the valves are represented by mesohalobic species (*Iconella hibernica* and *Tabularia fasciculata* dominate), the content of freshwater species is 35%, the content of indifferent species is about 10%. The diatoms concentration is over 100000 valves/cm³.

Layer 5 (2.10 - 1.40 m, 8.3- 4.2 ka). The content of organic matter varies from 18 to 52%, the content of carbonates varies from 6 to 68%, the content of terrigenous deposits varies from 15 to 42%. Silt dominates (65-76%), clay varies from 7 to 28%, sand varies from 4 to 20%. Values of magnetic susceptibility are extremely low (almost zero). More than 90% valves relate to benthic oligohalobic species, about 75% of them relate to halophobe species (*Cymbella subhimalaspera* dominates), the content of halophile species is about 3-5%, the content of indifferent species varies from 20 to 30%. The diatoms concentration decreased from 28000 to 10000 valves/cm³ toward to the bottom of the layer.

Layer 6 (1.40 - 0.45 m, 4.22.0 ka). Interlayers with a higher (7-14%) and lower (4-6%) content of organic matter are distinguished. The content of carbonates varies from 4 to 18%, the maximum content relates to the bottom of the layer. The content of terrigenous deposits varies from 67 to 91%. Silt predominates (57-78%), clay content varies from 17 to 38%, sand content varies from 0.3 to 12%. Values of magnetic susceptibility is moderately high ($0.15-0.35 \cdot 10^{-6} \text{ m}^3/\text{kg}$), peak values are located at depths 0.55 and 1.1 m. This layer relates to the formation of an "empty diatom zone" (although there are single valves).

Layer 7 (0.45 - 0.00 m, 2.0 - 0.0 ka). The content of organic matter varies from 6 to 12%, the content of carbonates varies from 3 to 20%, the content of terrigenous matter varies from 45 to 55%. Silt predominates, sand varies from 3 to 17%. Values of magnetic susceptibility are low (about $0.1 \cdot 10^{-6} \text{ m}^3/\text{kg}$). About 80-90% of diatom valves relate to benthic mesohalobic species (*I. hibernica* and *Anomoeoneis costata* dominate). The diatoms concentration increases from 20000 to 100000 valves/cm³ toward to the upper part of the layer.

There are three local pollen zones (LPZ) in the section. In the lower part of the section (LPZ 1, 320–240 cm) the content of tree and shrub pollen does not exceed 30% of the spectra. Pollen of forest-forming trees is represented mainly by pollen of spruce (*Picea*), Scots pine (*Pinus sylvestris*) and Siberian pine (*Pinus sibirica*) is present in approximately equal amounts (up to 15%). The proportion of non-arboreal pollen reaches 75% of the pollen spectra. Among the herbaceous plants, the pollen of haze (*Chenopodiaceae*), wormwood (*Artemisia*) and grasses (*Poaceae*) dominates; there is a large amount of pollen from the daisy (*Asteraceae*) and buckwheat (*Polygonaceae*) families. The total pollen concentration in LPZ 1 at the bottom of the section does not exceed 15000 pollen grains/cm³.

The content of tree and shrub pollen in LPZ 2 (240-120 cm) increases up the section from 25 to 65%. The pollen of *Poaceae* is about 15%. The content of *Chenopodiaceae* pollen in LPZ 2 decreases from 25 to 3-5% of pollen spectra. Pollen from coastal (*Sparganium*, *Alisma*) and aquatic (*Hydrocharis*, *Myriophyllum*) plants and numerous leaf spines of hornwort (*Ceratophyllum*) were found in LPZ 2. A huge number of sponge spicules is noted in the lowest sample from LPZ-2. The total concentration of pollen reaches more than 550000 grains/cm³.

In LPZ 3 (120–0 cm) the content of tree and shrub pollen decreases from 80% (the maximum along the section) to 40–50% of the pollen spectra. Among tree pollen, pine pollen dominates, and its content decreases from 40% at the bottom of LPZ 3 to 17% in the surface sediment sample. The content of *Poaceae* pollen remains at the same level (about 15% of the pollen spectra). There were found the aquatic plants pollen in LPZ 3 – the pollen of water milfoil (*Myriophyllum*) and pondweed (*Potamogeton*). The total pollen concentration generally does not exceed 250000 grains/cm³.

4. Discussion

The lithological composition of layer 1 likely indicates a highly dynamic sedimentation environment (a water flow). At the end of the Late Pleistocene (from 16.5 ka) and the beginning of the Early Holocene (up to 10.0 ka) the moderately shallow lake with highly flowing conditions and low bioproductivity (probably due to the cold climate) existed. At the end of the Early Holocene the water exchange of the lake decreased, and as a result the water salinity increased. In the middle Holocene, the water body desalinates, its level becomes unstable - probably, it could dry up completely in some extremely dry years. At the same time, the relatively warm climate contributed to high bioproductivity, the development of macrophytes and molluscs. In the first half of the Late Holocene (4.2-2.0 ka), the Belye Lakes were a shallow flowing reservoir with medium mineralization and moderate bioproductivity. The relatively high degree of flowability may be associated with increased of fresh water inflow at this stage. In the last 2.0 ka, the mineralization of the lake has increased,

which indicates a decrease in fluvial activity. The composition of pollen spectra and fossil flora in LPZ 1 allows us to conclude that during the Late Glacial, the dominant landscape in the Turano-Uyuk depression was grass-wormwood desert steppes having a sparse, open herbaceous cover. The associated development of erosion processes is confirmed by the findings of various *glomus* fungi spores (*Glomus spp.*).

Analysis of NPP showed that over time, the composition of green colonial algae *Pediastrum spp.* and cyanobacteria and the aquatic fauna became richer. The composition of pollen spectra and fossil flora in LPZ 2, which approximately corresponds to the Middle Holocene, reflects further climate amelioration, apparently expressed not so much in general warming as in a decrease in continentality and an increase in precipitation compared with the Late Glacial and the beginning of the Holocene. The productivity of the lake itself increased dramatically during this period - this is indicated by the abundance of colonial green algae (*Botryococcus*, *Pediastrum*) and the growing diversity of aquatic fauna. Findings of sponge spicules in LPZ 2 indicate the inflow of flood waters into the lake from the river Uyuk. Changes in the composition of sediments, pollen spectra and pollen concentrations of the main taxa in LPZ 3 can be explained by simultaneous cooling (increase in continentality) and aridization of the climate over the past 3000–4000 years.

5. Conclusions

The results of core study show that the lake sediments are underlain by red sands of the alluvial fans. The formation of the Belye Lakes began about 16.5 ka, which is marked by mineral loam at the base of core. Above, there is a three-meter layer of lacustrine sediments with significant variations in composition:

lacustrine loam in the lower and upper parts of the core, and peaty gyttia and lacustrine lime in the central part. In the time intervals 16.5-10.0 and 4.0-2.0 ka, the lake is characterized by moderate and high-flow conditions. The minimum flowability is typical for the periods 10.0-4.2 ka and in the last 2.0-0.0 ka. The lake has always been shallow, in the interval of 8.3–2.0 ka it could dry up periodically.

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Conflict of interest

The authors declare no conflict of interest.

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Diatom oxygen isotope records of Northern Eurasia as indicators of environmental, hydrological and climate changes in the regions

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ABSTRACT. The environmental, hydrological and climate dynamics were assessed in Northern Eurasia during the Holocene. The reconstructions are based on oxygen isotope composition of lacustrine diatom silica ($\delta^{18}\text{O}_{\text{diatom}}$) preserved in sediment cores from Ladoga, Bolshoye Shchuchye and Emanka lakes. Interpretation of the $\delta^{18}\text{O}_{\text{diatom}}$ data is supported by a comprehensive study of modern isotope hydrology and analysis of local and regional proxies. The Northern Eurasia $\delta^{18}\text{O}_{\text{diatom}}$ records are characterized by pronounced short term variations (1.5–5‰), pointing to the unstable climatic and hydrological conditions in the study regions. All records have clearly demonstrated a gradual depletion over the Holocene in their $\delta^{18}\text{O}_{\text{diatom}}$ values by ~3–4‰, which follows the trend of decreasing summer insolation, as well as the temperature history of the Northern Hemisphere (NH), indicating a positive response of diatom oxygen isotope signal to large-scale climate changes.

Keywords: stable oxygen isotopes, hydrological fluctuations, diatoms, climate change, lake sediments

1. Introduction

Lacustrine sediments are reliable archives, providing fundamental information on environmental and climate changes since the formation of a lake system (e.g. Subetto et al., 2017). In the last decades, diatom oxygen isotope analysis has become a dependable tool to trace hydrological and climate dynamics in individual lake catchments. Generally related to lake temperature (T_{lake}) and water isotope variations ($\delta^{18}\text{O}_{\text{lake}}$), $\delta^{18}\text{O}_{\text{diatom}}$ perfectly reflects these changes and is commonly applied in palaeoenvironmental and/or climatic reconstructions especially for northern regions where ice archives are unavailable and/or biogenic carbonates limited (e.g. Swann and Leng, 2009).

In the current study, the environmental, hydrological and climatic variability was reconstructed

from sediment cores of lakes located along a ~6000 km transect across Northern Eurasia, using diatom oxygen isotopes in the context of modern hydrology and other relevant local (diatom taxonomy, chironomid and biogeochemical analyses, isotope mass balance model) and regional parameters (modern moisture origin and digital elevation models). Combining the newly obtained $\delta^{18}\text{O}_{\text{diatom}}$ records with other regional and hemispheric reconstructions provides a complementary assessment of environmental conditions in normally intact, remote lake systems.

2. Materials and methods

The sediment cores Co1309, Co1321, Co1412 were respectively recovered from lakes Ladoga (60°59' N, 30°41' E; water depth: 111 m); Bolshoye Shchuchye

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(67°53' N, 66°19' E; water depth: 136 m); Emanda (65°18' N, 135°46' E; water depth: 14.6 m) during the drilling campaign within the German-Russian Paleolimnological Transect (PLOT) project (Fedorov et al., 2020), using gravity and percussion piston-corers operated from a floating platform (UWITEC Ltd., Austria).

Separation and cleaning of diatoms from the sediment matrix was carried out using a multistep process of wet chemistry, sieving, and heavy liquid separation described in detail in Kostrova et al. (2019; 2021). The oxygen isotope composition of purified diatom samples was measured at the ISOLAB Facility at AWI Potsdam with a PDZ Europa 2020 mass spectrometer using the laser fluorination method (Chapligin et al., 2010). A geochemical mass-balance approach (Chapligin et al., 2012) was applied for contamination correction of the measured $\delta^{18}\text{O}$ values.

3. Results and discussion

The $\delta^{18}\text{O}_{\text{diatom}}$ values from Lake Ladoga range from +29.8 to +35.0‰. The relatively high values between ~7.1 and 5.7 cal. ka BP are interpreted to indicate the Holocene Thermal Maximum (HTM). A continuous depletion in $\delta^{18}\text{O}_{\text{diatom}}$ after 6.1 cal. ka BP is related to Middle to Late Holocene cooling, which culminated in the interval 0.8–0.2 cal. ka BP corresponding to the Little Ice Age (LIA). Elevations/declines of the lake water level are accompanied by fluctuations in $\delta^{18}\text{O}_{\text{diatom}}$ towards lower/higher values, respectively. Thus, relatively low $\delta^{18}\text{O}_{\text{diatom}}$ values at ~10.7 cal. ka BP indicate that the lake existed as an eastern deep bay of the Ancylus Lake. The regression of the Baltic Sea and the formation of Lake Ladoga as an independent reservoir were accompanied by a decrease of the lake level and characterized by relatively higher $\delta^{18}\text{O}_{\text{diatom}}$. Between ~5.7 and 4.4 cal. ka BP, a decline in $\delta^{18}\text{O}_{\text{diatom}}$ values could reflect a lake level rise caused by the formation of a new inflow to the lake via River Vuoksi. The subsequent increase of $\delta^{18}\text{O}_{\text{diatom}}$ at 4.4–4.0 cal. ka BP gives an indication for a rather early opening of the Neva River outflow. An accelerated decrease in $\delta^{18}\text{O}_{\text{diatom}}$ after 4.0 cal. ka BP probably reflects an overall cooling with more persistent lake ice cover and reduced evaporation.

The Lake Bolshoye Shchuchye $\delta^{18}\text{O}_{\text{diatom}}$ record exhibits variations between +23.4 and +31.8‰. The short term (centennial-scale) variations often exceeding 5‰, especially in Middle and Late Holocene, are superimposed on the general decreasing trend. These fluctuations occur contemporaneously with and similarly to Holocene NH glacier advances. However, large Holocene glacier advances in the Lake Bolshoye Shchuchye catchment are unknown and have not left any significant imprint on the lake sediment record. Consequently, to explain the observed shifts for the deep and voluminous lake, about 30–50% of its volume should be replaced by isotopically different water within decades. Snow, which is known to be transported in surplus by redistribution from the windward to the leeward side of the Polar Urals, is

considered a likely source of water with a light isotope composition. Snow melt and influx changes are assumed to be the dominant mechanism responsible for the short term changes in the $\delta^{18}\text{O}_{\text{diatom}}$ record.

The $\delta^{18}\text{O}_{\text{diatom}}$ values from Lake Emanda vary from +22.5‰ to +27.8‰. An obvious shift in $\delta^{18}\text{O}_{\text{diatom}}$ at 11.7–11.5 cal. ka BP reflects the onset of the Holocene. Relatively high $\delta^{18}\text{O}_{\text{diatom}}$ during the Early Holocene suggests relatively warm and/or dry climate with associated evaporation effects. The absolute maximum in the record at ~7.9–7.0 cal. ka BP is supposed to be a Middle HTM. A continuous depletion in $\delta^{18}\text{O}_{\text{diatom}}$ values since ~5.0 cal. ka BP reaching the absolute minimum at 0.4 cal. ka BP is interpreted as Middle to Late Holocene cooling culminated at the LIA and associated with colder T_{air} , a more persistent lake ice cover and reduced evaporation. The pattern of the Lake Emanda $\delta^{18}\text{O}_{\text{diatom}}$ record is close to that obtained from Lake El'gygytgyn (Swann et al., 2010).

All $\delta^{18}\text{O}_{\text{diatom}}$ records follow a decrease in summer insolation and are in line with the regional and the NH temperature history, demonstrating a good response of the isotope signal to insolation-driven temperature changes. A consistent decrease in $\delta^{18}\text{O}_{\text{diatom}}$ is observed in the records from ~6.5–5.2 cal. ka BP, indicating Middle to Late Holocene cooling.

4. Conclusions

The Holocene oxygen isotope records on fossil diatoms extracted from sediment cores of lakes Ladoga, Bolshoye Shchuchye and Emanda are combined with the recent isotope hydrology and local proxy's data, and used to characterize the environmental, hydrological and climate variability in Northern Eurasia. The data revealed that all lakes existed during the Holocene as well-mixed freshwater bodies without any evidence of a brackish or marine environment. The variability of $\delta^{18}\text{O}_{\text{diatom}}$ is mainly controlled by changes in $\delta^{18}\text{O}_{\text{lake}}$ rather than changes in T_{lake} . However, in Ladoga and Emanda lakes it is also associated with enhanced evaporation effects, whereas evaporative effects are negligible in Lake Bolshoye Shchuchye. Here, local snowmelt may change the local $\delta^{18}\text{O}_{\text{lake}}$.

The Lake Ladoga region has undergone significant hydrological changes throughout the Holocene. The isolation of the lake basin in the Early Holocene, the subsequent opening of the Vuoksi River inflow at ~5.7 cal. ka BP and the formation of the Neva River outflow at ~4.4–4.0 cal. ka BP are accompanied by lake level changes and notable as respective maxima and minima in the $\delta^{18}\text{O}_{\text{diatom}}$ record.

The Lake Bolshoye Shchuchye $\delta^{18}\text{O}_{\text{diatom}}$ record displays short term, centennial-scale changes attributed to snow transport to the catchment and switch on/off of meltwater supply to the lake. The $\delta^{18}\text{O}_{\text{diatom}}$ signal is interpreted as indicator for palaeoprecipitation, whereas the decreasing long-term trend in the record follows summer temperature changes.

The Lake Emanda $\delta^{18}\text{O}_{\text{diatom}}$ record demonstrates striking similarity to that obtained from Lake El'gygytgyn (Swann et al., 2010) despite obvious hydrological

differences, suggesting a common “eastern” regional signal in both records.

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Conflict of interest

The authors declare no conflict of interest.

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Lakes of Eurasian interior, which significantly raised their levels in the recent past

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ABSTRACT. The paper presents geomorphological evidences of former appearances of huge lakes in Mongolia and in the south of Siberia visible on satellite images. Most of lakes in Mongolia and transboundary Russia are terminal basins collecting waters from catchments of large rivers draining the Altai, Khangai and Khentey Mountains, while in the south of Siberia such lakes had no sizeable sources for water input. The discussing reasons for these rises are obviously climatic with possible high influence of deglaciation processes in the surrounding mountains.

Keywords: geomorphology, remote sensing, paleolakes, terminal basins, lake level changes, Mongolia, Russia, Central Asia

1. Introduction

There are three regions of Mongolia, where lakes of this type occur: 1) the Great Lakes Depression in its north-west; 2) the Valley of Lakes (sometimes called the Valley of Gobi Lakes) in the south-west; and 3) the north-eastern part of the country (Fig.). All they are parts of the Central Asian Internal Drainage Basin; this means that the lakes under consideration (most of them) are terminal (endorheic), and collect waters from the surrounding mountain ranges. The bounding ranges of the Great Lakes Depression are Tannu-Ola (West and East) in the north, Mongolian Altai in the west and south-west, and Khangai in the east. The Valley of Lakes extends between the Gobi Altai and Khangai Mountains. The north-eastern region has no distinct orographic boundaries and locates eastward, south-eastward of the Khentey (Khentii in Mongolian) or Yablonoy (Yablonoviy in Russian) ranges. The regions consist of a number of separate terminal basins, which include one or two terminal lakes (lake systems) or, in case of the Khyargas Nuur, a system of intermediate lakes.

2. Materials and methods

For the geomorphological analysis of the lake basins presented in this paper, we used the following data sources: general topography from the Russian army map, the Google Earth Pro Earth visualization software with its embedded NASA SRTM DEM topographic data, and the Wikipedia public domain data about the lakes

and their basins. The data refer elevations based on different vertical datum; therefore the elevations may differ due to this factor. Additionally, the lake levels may vary with a time, which is also reflected in the elevation marks in the used topographic sources.

3. Results

Brief description of lakes

Uvs Nuur. This is the largest lake of Mongolia by its area - 3350 km² (Fig.). With maximum depth 20 m and average 10.1 m, its volume is 35.7 km³. The lake has map altitude of 759 m a.s.l. The shorelines rising 10 m above the lake are better seen in its northern and south-eastern banks. The upper shorelines obviously cut the previously formed piedmont fan systems; however, without any erosional scarp. The area of the lake at its highest stand seemingly did not rise considerably, whereas the volume increased more than two times and could reach 90 km³.

Uureg Nuur occupies a small depression inside the Mongolian Altai westward of the Uvs Nuur (Fig.). The lake area is 239 km² and volume is 6.4 km³; maximum depth. 42 m and average depth 26.9 m. The basin lies at the altitude of 1425 m a.s.l. The banks of the lakes have a stair of shorelines rising 55 m above its modern water surface. This means three times increase of the volume of the lake which could reach 20 km³.

Khyargas Nuur and **Airag Nuur** located in the central part of the Great Lakes Depression form a largest terminal basin of Mongolia by its capacity to store water (Fig.). Modern levels of the lakes are 1028

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Fig. Google Earth based map of Mongolia and transboundary Russia showing location of the investigated lakes and largest mountain ranges. Yellow line – country boundaries. Red line – boundaries of the lake catchments (Krivonogov et al., 2020).

and 1030 m a.s.l., respectively. The terminal Khyargas Nuur is deep-water with maximum depth of 80 m. Its average depth is unclear; different sources give it in the range from 31 to 50.7 m. Correspondingly, the area estimates vary from 1468 to 1481 km² and volume from 66 to 75 km³. The intermediate Airag Nuur is located to the south of the Khyargas Nuur and is connected with it by a narrow river-like Nuurn-Kholoi channel. It accepts the major rivers flowing to the basin and annually transfers 1.2 km³ of the water to the main basin. The area of the lake is 143 km². The maximum and average depths are 10.5 and 5.7 m, respectively.

Lakes Khyargas and Airag are surrounded by the shorelines rising 115 m above their current level. They represent a huge lake approximately three times larger in area and many times larger in volume than the modern one, with the maximum depth of 195 m. This rise suggests a huge amount of water delivered from the catchments. The catchment of the Khyargas Basin is very large, about 180,000 km². It comprises the Zavkhan Gol valley and valleys of its tributaries, the largest of which is Khovd Gol. If the Zavkhan Gol flows directly into the Airag and Khyargas lakes, the Khovd Gol ends by a delta in the Khar-Us Nuur. From this lake, the waters arrive to the Khar Nuur by the short Chono-Kharaikhyn Gol and farther to the Zavkhan Gol by the Teeliin Gol. These lakes and their linked Dorgon Nuur, form a system of intermediate lakes, where the waters of the Khovd Gol diminish by evaporation.

Boon Tsagaan Nuur – Adagiin Tsagaan Nuur system. This is a terminal basin for the Baidragin Gol (295 km long, catchment about 28300 km²) (Fig.). The whole depression is rather flat and the river delta serves as a topographic divide between its western and eastern parts, where the lakes locate. Altitudes of the lakes are: the Boon Tsagaan Nuur 1313.4 m a.s.l. and the Adagiin Tsagaan Nuur 1283.8 m. The western shores show the stair of shorelines up to 1317 m a.s.l. and rare bars up to 1321 m a.s.l. The eastern bank of the Adagiin Tsagaan Nuur has a distinct stair of shorelines ascending up to 1341 m a.s.l. which is 49 m higher than the former stable level of the Adagiin Tsagaan Nuur and 29 m higher than the surface of the Boon Tsagaan

Nuur. This means that a single lake as large as 2026 km² and about 90 km³ formed at this level.

Orog Nuur – Taatsiin Tsagaan Nuur system. The Orog Nuur and Taatsiin Tsagaan Nuur are terminal basins for the Tuin Gol and Taatsiin Gol, respectively, with total catchment about 21800 km² (Fig.). The Orog Nuur has altitude 1221 m a.s.l., area 140 km², and volume 0.42 km³. Its maximum depth is 5 m and average depth 3 m. The lake is surrounded by a stairs of shore bars rising up to 1274 m. a.s.l. The 1266 m a.s.l. level of the Orog Nuur is controlled by a spillway to the Taatsiin Tsagaan Nuur basin. The lake is a dry salty silty plain in our days. The dry bottom on Google Earth is 1236 m a.s.l. In the western edge of the basin, the spillway from the Orog Nuur opens to the plain at 1255 m a.s.l. In the northern edge of the Taatsiin Tsagaan Nuur shorelines are seen at 1243, max. 1245 m a.s.l.

The Torei lake system. The Zun-Torei and Barun-Torei lakes occupy the Torei Basin, a tectonic depression inside low mountainous Siberian and Mongolian Transbaikalia (Fig.). The lakes considerably change their level and form a single lake, two separate ones or even dry out depending on water supply. The lake is fed by the larger Uldza River (425 km long, catchment 26,900 km²) and smaller Imalka River (156 km long, catchment 1480 km²). The Barun-Torei Lake at higher water level of 598 m a.s.l. has maximal depth 6 m, area 580 km², and volume 1.38 km³. The terminal Zun-Torei Lake at the water level of 600 m a.s.l. has average depth 1.5-1.6 m and maximum 6.7 m; the area reaches 302 km² and volume 1.62 km³. Shorelines show ancient rises of the Torei lakes; the merged lake reached 616 m a.s.l., i.e. 20 m above the modern (596 m) level. At this level, the lake waters overflowed the basin watershed and discharged southward to the Khukh Nuur lake system via the Teliin Gol River.

Khukh Nuur occupies a terminal basin in the Onon-Kerulen rivers interfluvium (Fig.), which is the most lowland territory of Mongolia. It is the lowest place of Mongolia, altitude 560 m a.s.l. The lake surface is 566 m a.s.l., the area is about 67 km². Google Earth shows multiple shorelines around the Khukh Nuur rising to about 603 m a.s.l. At this level, the waters should cover

the adjacent lake basins eastward of the Khukh Nuur; there are spillway channels between the lakes and poorly seen shorelines. Watering of the basin is linked to the evolution of the Torei lake system.

Yakhiin Nuur locates in the south of the Eastern (Dornod) Province of Mongolia. The lake is a terminal basin in the southern part of the Onon-Kerulen interfluve (Fig.). Modern lake level is 660 m a.s.l., Mongolian Wikipedia reports area 97 km² and volume 0.223 km³ at the level 670 m a.s.l., maximum depth 4 m and average depth 2.3 m. The lake is fed by the Galiin Gol River; total area of the lake catchment is about 7000 km². Shorelines around the Yakhiin Nuur rise to about 705 m a.s.l. This means the lake level increased 47 m above the modern one.

4. Discussion

Several publications reveal histories of the described basins in Western Mongolia, e.g. Lehmkuhl et al. (2018). A limited number of published OSL and ¹⁴C dates infers rises of the lakes during the Holocene; however, detailed timing of the described high stands of the lakes is still unclear. Another problem is water sources. Researchers link the rises with moisture evolution (Wang and Feng, 2013), fluvial catastrophes (Agatova and Nepop, 2019) or deglaciation of the surrounding mountains (Krivonogov et al., 2020).

5. Conclusions

The presented remote sensing data on the lakes and age constraints available for the lakes give us ground to declare this problem as unsolved in part of timing,

lake catchment history, and general understanding of climatic processes in northern Central Asia.

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Conflict of interest

The author declares no conflict of interest.

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Bottom sediments of the Eastern part of the Onega Peninsula Lakes in the context of the White Sea relative level changes

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ABSTRACT. Geomorphological, ground penetration radar profiling and paleolimnological investigations were carried out in the Kobyl'e (11 m asl), Chevakin (7 m asl), and Lopshen'gskoye (1 m asl) Lakes. Based on the lithology data, we obtain the relative sea-level (RSL) changes in the northern part of Gulf of Dvina (White Sea, Arctic Ocean) during the Holocene. The levels of two transgressions (Late Glacial and Tapes) and one Early Holocene regression are identified. According to the lithology composition of bottom sediments, investigated lakes has a longer transitional stage, then lakes in 22 km to the south.

Keywords: sea level change, Holocene, paleolimnology, Tapes, White Sea, Letnij coast, isolated basins, lithology

1. Introduction

Changes in the relative level of water basins on the periphery of Scandinavian Ice Sheet (SIS) since the Last Glacial Maximum (LGM) were caused by glacioisostatic adjustment (GIA) due to changes in the load of the ice mass, vertical tectonic movements, glacioeustatic and eustatic fluctuations in the volume of water in the sea basin (Mitrovica et al., 2011), and changes in wave activity (e.g., Møller et al., 2002). A complex combination of global, regional, and local phenomena determines the differences in RSL dynamics along the shoreline of reservoirs. The aim of this study is collect and obtain new paleolimnological and lithological data in context of RSL changes and compare these data with published results. It is important for constraining regional paleogeographic reconstructions, understanding the patterns of development of coasts on the periphery of Late Pleistocene ice sheets, and verifying models of RSL dynamics.

2. Materials and methods

Study area. The studied lakes are located in the northern part of the Onega Peninsula of the White Sea. On the landward side, the lake cores adjoin the marginal structures of the Neva degradation stage of the last

glaciation (Zorenko et al., 2000), and on the seaward side, they are bounded by disconnected, low (up to 20-30 m) moraine ridges and hills. At heights of 10-15 m, gently sloping abrasion and abrasion-accumulative terraces developed on their apical surfaces and slopes, the formation of which may be compared to the Late Glacial transgression (~13-11.5 ka BP) (Kolka and Korsakova, 2017). According to (Zorenko et al., 2000), the deposits of this transgression-sands, sandy loam, and clays-can be traced to ~20 m a.s.l. However, we did not find any morphological evidence of the impact of coastal processes on the glacial topography at elevations higher than 15 m.

The basins of the lakes Kobylie and Chevakin are located in a depression of complex configuration, have irregular plan outlines and are connected to each other by a dry channel. With the position of the relative sea level at the marks of 11 m and more, they were probably parts of a single system of straits that connected the estuary of the Malaya Syarta River to the Sea. At present, Lake Chevakin is undrained. The runoff from Lake Kobylie is carried out by the Malaya Syarta River, flowing in the south and flowing out in the north of the basin.

The Lopshenga Lake basing formed in the mouth part of the Lopshenga estuary and located in an elongated depression.

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Methods. Field investigations included DGPS and surveys, geomorphological and ground penetration radar profiling and coring of the lake sediments.

Coring was carried out from the ice using a Russian peat corer. It was accompanied by lithological and stratigraphic description according to the methodology (Subetto, 2009) and core sampling for analytical studies and radiocarbon dating. GPR studies were carried out using Zond-12e ground penetrating radar and 300 MHz antenna (average depth - up to 10 m, resolution - first tens of centimeters). The first results of core analyses were obtained.

3. Results and discussion

According to the lithological and stratigraphic description of the cores, five horizons are distinguished in the section of bottom sediments of the Kobyl'e Lake (320-967 cm from the water surface). On the dense sandy silt-gray loams with macrofossils (1) lies peat with wood fragments (11 cm) (2); its accumulation by analogy with the same sediments from Lake Murakanskoye (Kublitskiy et al., 2022), can be tentatively correlated with the regression of the Early Holocene. This layer is overlying by peaty silt and replaced up the section by stratified and thinly stratified silt of gray-brown to grayish-olive color (168 cm) (3). Higher up, interbedded gray-bear, brown, and light gray sandy silt occur (145 cm) (4). The lower half of the sequence contains peat layers and wood detritus. The composition of the sediments indicates variable conditions of their accumulation, which could possibly be related to the proximity to the seashore during the Tapes transgression. The upper horizon of the section is represented by lake sediments - homogeneous brown gyttja, sometimes enriched in silt] (330 cm) (5).

The bottom sediments of Lake Chevakino (280-920 cm from the water surface) have a similar overlaying character. However, the composition of horizons 3 and 4 is not identical to similar horizons from Lake Kobyl'e. Above the peat (4 cm), there are gray and dark gray sandy and clayey silt, homogeneous or with periodic stratification, containing microfossils of plants and, possibly, hydrotroillite (201 cm) (3). The silt of the "motley" horizon (180 cm) (4) contain more sand and fewer organic inclusions. Probably, this layer have accumulated at the end of the Tapes transgression, at the stage of separation of the enclosed bay from the sea.

The bottom sediments of Lake Lopshenga (180-938 cm from the water surface) have a more complicated structure. In the lower part of the section, dense sandy loams with reddish and black admixes (1) were uncovered (20 cm), probably it is rewashed glacial sediments. Above them, loamy sands with plant fragments (32 cm) (2), overlain by silt (11-20 cm) (3) and then by sandy silt with detritus and whole clam shells (101 cm) (4), with an erosional contact. The grain-size composition of the sands indicates a gradual increase and then a decrease in hydrodynamic activity. M.A. Lavrova (Lavrova, 1931) attributes similar deposits

described in the basement of 4-7 m high terraces near the village of Yarenga and in some other areas of the Onega Peninsula to the final stages of the Late Holocene transgression. In the delta of the Northern Dvina River, sands with marine mollusk fauna are underlain by Early Holocene peat (Koshechkin, 1979). The transitional horizon (5) has a considerable thickness (436 cm) and is represented by interstratification of gray, black, and dark olive sandy silt with plant remains and isolated wood fragments. The grain-size composition of the upper horizons of the section consisting of sandy-silty gyttja (52 cm) (6) and sandy silt (42 cm) (7) suggests fluctuations in hydrodynamic activity during the final stages of sediment accumulation.

Comparing the results with previous studies conducted 22 km south of the site (Kublitskiy et al., 2022), we can state a difference in the lithological structure of the bottom sediment strata. The lakes considered in this paper have a thick horizon of stratified sandy silt, while in the lakes located to the south, this horizon is thin. This peculiarity may indicate more prolonged transitional conditions in the studied lakes.

4. Conclusions

During the maximum Late Glacial transgression (~13-11.5 ka BP) (Kolka and Korsakova, 2017), the relative sea level was apparently ~15 m higher than today. Terraces were formed on the slopes of the moraine ridges and estuaries existed in the estuaries of the Lopshenga, Bol'shaya and Malaya Syarta. During the Early Holocene regression (~11.5-9.8 ka BP) (Kolka and Korsakova, 2017), the basins of Lakes Kobyl'e and Chevakino were drained. No traces of regression were found at the mouth of the Lopshenga River. Apparently, the estuary of the river shifted after the receding sea, and its channel cut into the previously accumulated sediments, destroying them. In the Middle Holocene, during the Tapes transgression (~8.2-5.8 ka BP) (Repkina et al., 2020), the relative sea level reached ~9 m and then gradually declined. Terraces with heights of 7-9 and 5-6 m above the modern sea level were formed. In the Late Holocene, the relative sea level gradually decreased, and terraces at 2.5-3 m and then the modern one (up to 1 m) were formed.

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Conflict of interest

The authors declare no conflict of interest.

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Geochemical features of river runoff and its influence on sedimentation processes in Lake Onego

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ABSTRACT. Suspended matter entering Lake Onego with river runoff was studied from 2019 to 2021. Observations on rivers in different seasons on the basis of an interdisciplinary systematic approach combining modern landscape-geographical, biogeochemical, mineralogical, geochemical, hydrochemical, ecological methods allowed us to gain new knowledge about the weighted average flow of substances into Lake Onego for seasonal variability.

Keywords: big lake, Lake Onego, suspended matter, geochemical composition of sedimentary matter, geochemistry, metals

1. Introduction

Lake Onego (61°42' N, 35°25' E) is the second largest freshwater lake in Europe (the area of the lake is 9,720 km²) and one of the largest reservoirs of the Russian Federation, belongs to the Baltic Sea basin. The geological structure, orography, climatic conditions, vegetation and hydrography are different over the entire significant area of the lake's catchment area (53,100 km²). In 2021, work continued with the study of the lake's suspended matter and suspended matter entering Lake Onego with river runoff (Kulik et al., 2022). To assess the flow of substances into Lake Onego with river waters, work continued on the survey of 9 of its tributaries and the Svir River, among them are three large rivers - Vodla, Shuya and Suna, which give 68% inflow into the lake.

2. Materials and methods

According to the geographical location of the catchments, the objects of study were grouped based on the geological and geomorphological structures of the lake basin. Thus, the investigated rivers - Lososinka, Shuya, Suna (Northwest coast) and Kumsa (North coast) and Vodla (East coast) drain the territory of the Archean-Proterozoic Fennoscandian Crystalline Shield (FCS), the Vytegra River (South coast) drains the territory of the East European Platform, and the Andoma River (Southeast the coast), Sheltozerka and Derevyanka (Southwest coast) are located at the junction of two geological structures (Atlas of the

Republic of Karelia, 2021). The Svir' River is the outlet from Lake Onego (Fig.).

The surface water was sampled into ten-liter polyethylene cans. In laboratory conditions, the aqueous suspended matter was divided into dimensional fractions by sequential filtration through membrane filters with different pore diameters. The analysis of the chemical composition of water samples (pH, NH₄⁺, NO₃⁻,

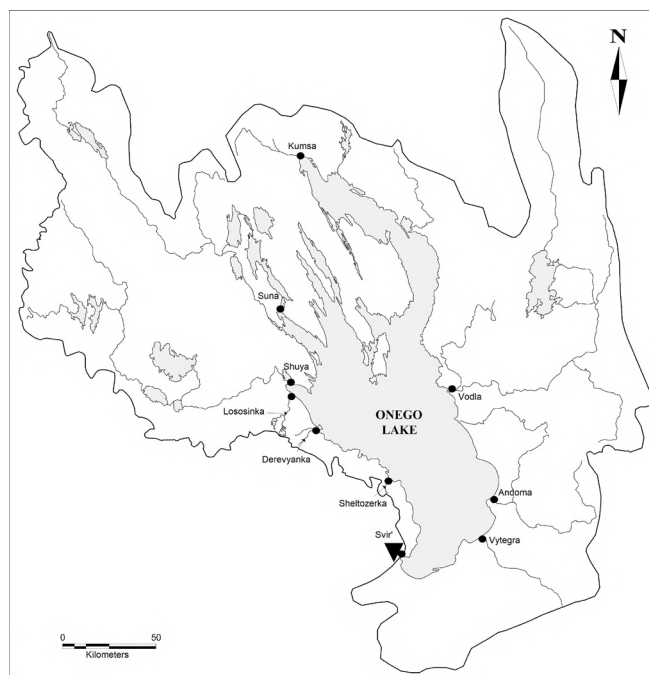


Fig. Schematic map of Lake Onego with sampling points.

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N_{total} , $P_{mineral}$, P_{total} , BOD5, permanganate index, COD, Si, color of water) was carried out in the NWPI KarRC RAS according to the methods generally accepted in the hydrochemical research (Zobkov et al., 2022). The micro-component composition in water and aqueous suspended matter was analyzed in the NWPI KarRC RAS by atomic absorption (AA6800, Shimadzu) and mass spectrometric ICP-MS (Agilent 7500a) methods on the scientific equipment of the Core Facility of the Karelian Research Centre of the Russian Academy of Sciences and the analytical Centre of the IGM SB RAS (Novosibirsk).

3. Results and discussion

3.1 Water samples

Mineralization of rivers located in the catchment of the Archean-Proterozoic Fennoscandian Crystalline Shield varied from 11 to 60 mg/l for the observation period. Mineralization the Vytegra River draining over limestone carboniferous is much higher from 110 to 193 mg/l. The waters of the studied tributaries are related to the bicarbonate-calcium type. The ratio of calcium and magnesium ions are determined by the geochemical conditions of the lake's catchment basin. Concentrations of alkali metals are insignificant. In the anionic composition, attention should be paid to the content of anions of organic acids - their increased content was observed in rivers with a heavy swampy catchment (Sheltozerka, Derevyanka, Andoma). Like most rivers of the Taiga zone, the studied tributaries are enriched with humus substances, which causes a high content of $C_{organic}$. During the year, the maximum content of P_{total} in all the studied rivers was occurred for summer and winter. Of the forms of N in the tributaries, the organic form prevailed.

The lowest concentrations of dissolved silicon were obtained for the summer. The exception was the Sheltozerka and Derevyanka Rivers, when the silicon content increased 1.5 times in summer compared to spring. Silicon enters river waters mainly as a result of leaching of acidic igneous rocks on Lake Onego catchment. Such an increase may be due to the acceleration of denudation processes in red-colored and gray-colored quartzite sandstones with an increase in temperature and the active removal of Aeolian material from open pits in the summer.

The Svir' River is an outlet from Lake Onego, the chemical composition at its source is determined by the lake regime. The waters of the river, as well as all tributaries belong to the bicarbonate clash of the calcium group. In the anionic composition, sulfate ions predominate over chloride ions. The content of organic matter and biogenic elements in the waters of the river is lower than in the studied tributaries and is mainly determined by the flow of intra-reservoir processes in Lake Onego. There were no significant seasonal fluctuations in the chemical composition of river water for the year.

The average concentrations of most elements obtained as a result of research do not significantly

differ from those in the global river flow (Gaillardet et al., 2003; Savenko, 2006). Some discrepancies in comparison with the values of the world runoff were obtained for Fe, Zn and Pb. High concentrations of iron are associated with regional peculiarities. The excess of Zn and Pb for some rivers is probably due to anthropogenic influence, this issue requires further study.

3.2 Suspended matter

During the sequential separation of the suspended matter in the studied water samples into coarse and fine suspended components, the predominance of suspended particles > 0.8 microns was observed.

Electron microscopic examination (SEM) of suspended matter showed that the content of the mineral component was closely to ones from the many rivers of the Arctic territories. We have identified similar spectra of suspended matter minerals in rivers. However, more uneven distributions were in particle sizes, degree of rolling and relationship with organic matter. According to the SEM results, the suspended mineral part is represented by an aggregated substance of lithogenic particles of different dimensions in association with frustules and biotritite of diatoms. Among the mineral particles (1-5 μm) grouped into aggregates (with a diameter of 15-40 μm), quartz grains, irregular grain clots of hydroxides and carbonates Fe, Mn, plagioclase (albite, oligoclase, andesine), potassium feldspar, muscovite, illite (Mg, Fe), chlorite (Mg, Fe) predominate. It is important to note that illite and chlorite with Mg and Fe content in approximately equal amounts sharply prevail in the suspended matter of the rivers, and their large leafy aggregates begin to be replaced by ferruginous varieties of illite and chlorite.

Contents of trace elements are characterized by an increased content of Mn, Fe, Cu, Mo, Cd, Sb and Pb, contents of other metals are comparable with the contents in the rivers of the World (Viers et al., 2009; Shevchenko et al., 2010; Chudaeva and Chudaev, 2011). The increased content of the metals is probably related to the geological features and diversity of the soil cover of river catchments.

Thus, the geochemical features of Karelian landscapes are a high degree of swampiness of the territory and an increased Fe content in the soils. This element enters water bodies from the catchment area in combination with humus substance and is a sign of Fe-Mn of the province (Belkina et al., 2018.). According to published data (Fedorets et al., 2015), a significant amount of Mn accumulates in the forest litter of the region, and in some territories significantly exceeding the maximum permissible concentrations (from 1.5 to 5 times). According to the literature data, the proportion of the suspended form of Cu increases due to the receipt of terrigenous and biological material from the catchment area of rivers and depends on the season (Belkina et al., 2012). The data obtained in our study on the content of Cd are 9 times higher than the global values. According to the literature data, the Cd content in soils increases significantly in the areas of

sulfide deposits characteristic of the Karelo-Kola region (Dauvalter and Kashulin, 2015). Using the example of Fe, Mn and P_{total} , the seasonal course of the distribution of migration forms of these elements in the tributaries and the source of Lake Onego was considered.

4. Conclusions

Observations on rivers in different seasons on the basis of an interdisciplinary systematic approach combining modern landscape-geographical, biogeochemical, mineralogical, hydrochemical, ecological methods allowed us to gain new knowledge about the weighted average flow of substances from river waters into Lake Onego, their mineralogical composition and seasonal variability of the geochemical composition of river waters. Quantitative estimates of sedimentary matter intake from various sources have been performed. The nature of the spatial seasonal heterogeneity of the distribution of microparticles in the river suspended matter entering the lake and its rather monotonous mineral composition is shown. Despite the similarity of the main chemical characteristics due to the common climatic conditions of the entire catchment basin, due to the heterogeneity of its geological and geomorphological structure and hydrographic features, the chemical composition and regime of river waters within the region differs.

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Conflict of interest

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Short communication

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Lake sediments of the Kindo Peninsula and its surroundings (Karelian Coast of the White Sea) – Holocene stratigraphy and dynamics of organic accumulation

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ABSTRACT. Sediment stratigraphy and dynamics of organic accumulation of eight small isolation basins at the Kindo Peninsula and its surroundings (Karelian Coast of the White Sea) were studied. The sediments structure and organic matter dynamics were found to depend on the age of the isolation that, in turn, depends on the lake's elevation. The thickest gyttja layer (up to 3 m) with loss-on-ignition values ca 60% formed in the lakes at the highest elevations. The thickness of marine-lacustrine transitional units varies from few cm to tens cm. The earlier isolation from the sea took place the thinner the transitional unit. In the lakes where isolation has not finished yet, the transitional sediments with LOI values ca 20-30% still form.

Keywords: lacustrine sediments, organic matter in lake sediments, loss-on-ignition, isolation basins

1. Introduction

The area of the Kindo Peninsula and its surroundings (the Karelian Coast of the White Sea), has turned into a testing ground for detailed natural science research, including studies of isolation basins, due to the White Sea Biological Station of the Moscow State University (e.g. Krasnova et al., 2016). The isolation basins are the lakes that once were sea bays and lost their connection to the sea in the past, or have been still isolating and thus experiencing an irregular influence of the sea. Studying the isolation basins provides important information both for the hydrochemistry and hydrobiology of the isolation process, and for paleogeographic reconstructions, primarily those devoted to the relative sea-level changes. Some results of the isolation basin studies at the Kindo Peninsula in the context of reconstruction of the Holocene shoreline displacement of the White Sea have been published elsewhere (Dreßler et al., 2009; Romanenko and Shilova, 2012). The dynamics of organic matter in the sediments provides important stratigraphic markers for studies of isolation basins. Studies of the organic matter content in the sediments of some recently isolated or currently isolating lakes at the Kindo Peninsula and the surrounding area were performed (Dreßler et al., 2009;

Vakhrameeva and Losyuk, 2020; 2021). However, there are still few studies of the organic matter dynamics in sediment sequences covering pre-isolation, isolation and post-isolation stages, while the others were focused on the uppermost part of the sequences.

The present study provides information on the stratigraphy and organic matter content in the sediments of 8 lakes at the Kindo Peninsula and the surrounding area. Retrieving the sediment cores from the central part of the lake basins, i.e. the integrated sedimentation point, provided discontinuous sediment successions.

2. Materials and methods

Sediment cores from 8 lakes were retrieved from the isolation basins located at different elevations. Some of the study lakes still receive the seawater during the springtides (Fig., Table). The coring was performed with a Russian peat corer from the central parts of the lakes from a floating platform (in autumn 2018) or from the ice surface (in spring 2019). Limnos sediment sampler was applied to collect the uppermost (up to 40 cm) sediments. In some lakes, a transect coring was carried out at different depths. The organic matter content in the sediments was studied using the loss-on-ignition

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Table. List and characteristics of the study lakes (the lakes' elevations are from Dreßler et al. (2009), Romanenko and Shilova (2012), Krasnova et al. (2016)).

Lake, coring site №	Elevation above sea level, m	Area, 10 ³ m ²	Depth at the sampling point, m	Sediment thickness, m	Gyttja thickness, m (LOI average value, %)
Verkhnee, 1	87	17.1	2.1	3.1	3.0 (61)
Vodoprovodnoe, 1	72	2.9	3.0	3.2	2.6 (64)
Krugloe, 1	27.5	5.4	2.0	1.8	1.7 (60)
Verkhnee Ershovskoe, 1	2.3	100.3	1.5	0.2	0.1
Nizhnee Ershovskoe, 2	1.6	79.9	2.8	1.1	0.9 (24)
Kislo-Sladkoe, 18-2	<1	16.7	4.1	1.6	0.6
Trekhtsvetnoe, 2	<1	35.2	3.4	2.3	0.3
Lagoon on Cape Zelenyj, 1	<1	19.1	5.9	2.8	0.5

(LOI) analysis following to the procedure adopted at the Institute of Limnology (500-550°C, 6 hours). One and 2-cm thick samples were discontinuously collected from corer.

3. Results

The lower parts of the sediment sections consist of sands/silts replaced by gyttja upwards. Depending on the lake's elevation above the sea level, two stratigraphic types are distinguished. In the lakes with no connection to the sea, there is a complete sediment sequence, with a thin transitional unit between the lower minerogenic sediments and the upper gyttja. The transitional sediments are sandy gyttja, occasionally laminated. In the lakes at the final stage of isolation, the sediment sequence is incomplete, and the transitional sediments represented by occasionally laminated gyttja, still form above the sands/silts. The lamination appears in sediments accumulated in deeper parts of a lake.

The dynamics of the organic matter content corresponds to the lithostratigraphy of the sediments. In the lower, mineral sediments, the LOI values range from 0.2 to 6.7%. The average LOI values in gyttja are about 60-65% ranging from 13 to 77%. In the lower part of gyttja in the lakes Vodoprovodnoe and Verkhnee, an episode of moderately high (about 50%) organic matter content is distinguished followed by the subsequent growth to the highest values.

In the currently isolating and recently isolated lakes, the organic matter content is not as high. For instance, in the upper part of the transitional gyttja in the lakes Kislo-Sladkoe and Trekhtsvetnoe the LOI values are about 20-30%. Besides, different trends in the organic matter dynamics were observed in the upper 10 cm of the sediments from Lake Kislo-Sladkoe collected from different depths. In the sediments retrieved from 3-m depth an upward increase in LOI was recorded, while in the core obtained from 4-m depth LOI values decrease upwards.

4. Discussion and conclusions

The maximum thickness of gyttja (3 m) was observed in Lake Verkhnee, located at the highest elevation, and consequently isolated from the sea earlier than the others. The earliest date obtained from

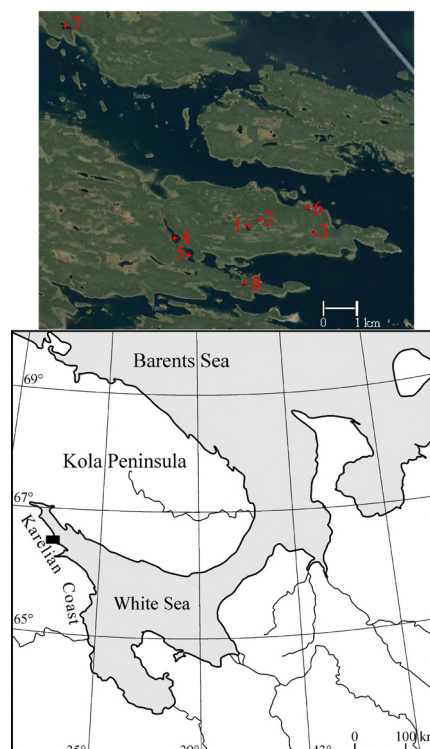


Fig. Location of the study sites (lakes are indicated by the numbers they are given in the table).

the bottommost part of the organic sediments from the peat bog surrounding the lake is about 9400 cal. yrs BP (Romanenko and Shilova, 2012), allowing an approximate estimation of the sedimentation rate in higher-elevated lakes after the isolation to 0.3 mm/year.

Our results enable identifying several characteristic features of the accumulation of organic matter in the sediments of the study lakes. Organic-rich sediments with an organic matter content of 60-70% formed in the lakes located at higher elevations (Verkhnee, Vodoprovodnoe and Krugloe). In the lakes that have recently lost the connection to the sea or are still isolating (Nizhnee Ershovskoe, Kislo-Sladkoe, Trekhtsvetnoe), the organic matter content in the transitional sediments is much less, about 20-30%. These values are consistent with the data previously obtained from the sediments corresponding to the transition from sea to lake, retrieved from the isolation

basins at the Solovky Archipelago (Ludikova et al., 2021; Kuznetsov et al., 2022).

The difference in the trends of organic matter dynamics recorded in the recent sediments of Lake Kislo-Sladkoe collected at different lake depths can be attributed to different chemical sedimentation environments in meromictic lakes that retain salt waters in their deepest parts. Another possible explanation could be in the diagenetic transformations unevenly occurring in the recently accumulated sediments.

The process of the isolation from the sea at the beginning of the Holocene differed from the recent one in terms of the organic matter accumulation. In Verkhnee and Vodoprovodnoe lakes, an explosive increase in organic matter was recorded in the transitional – post-isolation sediments while in Lake Krugloe this growth is smoother and can be traced in about 20 cm of sediments. In Trekhtsvetnoe and Kislo-Sladkoe lakes where the isolation process started in the second half of the 20th century, transitional organic-rich sediments still form, and their thickness can exceed 40 cm.

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Short communication

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Paleohydrological events and ancient man in the valley of the Western Manych River (the Ponto-Caspian region, Russia)

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ABSTRACT. This article discusses the interaction of ancient man and the aquatic environment in the Western Manych River Valley.

Keywords: Late Pleistocene, Late Paleolithic, Manych River Valley, Khvalyn transgression

1. Introduction

The valley of the Western Manych River, due to its low position, served as a water exchange route between the Black and the Caspian Seas (Danilevskiy, 1869). Many researchers have been studying the structure of the Manych Valley, however, hypotheses about an origin of the Manych Valley for the Pleistocene were primarily based on assumptions of Popov (1983).

The Manych depression was filled with sea water from the end of Pleistocene (the Early Khvalynskaya transgression, + 50 m abs.) At the same time, there was a flow of Caspian waters through the Manych depression into the Azov Sea and the Black Sea (Novoevksinsky basin, -50, -100 m abs.) (Yanina, 2006; Chepalyga et al., 2007).

The Manych Valley is located on the border between Europe and Asia and it is likely a migration route for the ancient population. Many researchers have been searching for Paleolithic monuments in the Manych Valley, however, until the end of the twentieth century, only few Mesolithic sites were known here. Thus the site Yulovskaya of Late Paleolithic was discovered in 1994 in clear stratigraphic conditions on the left bank of the Zapadny Manych River (Simonenko, 1998). The site was investigated by a team of the Don Archaeological Society led by Tsybriy in 1997 (Tsybriy, 2000). Later the site was studied by the Paleohydrological group of the Institute of Geography of the Russian Academy of Sciences (A. L. Chepalyga, N. V. Lavrentyev et al.) and the Biodiversity Laboratory of the Research Institute of Biology of the Southern Federal University (O. N. Demina et al.), with the support of the Don Archaeological Expedition of Moscow State University during 2006-2008.

Currently, the main research materials on the Late Paleolithic site of Yulovskaya have been published

(Lavrentyev et al., 2012). However, the malacofauna of the Khvalyn transgression was not found in the sediments of the Late Paleolithic site of the Yulovskaya. Therefore, it was not possible to link the cultural layers of the Late Paleolithic site of Yulovskaya to the Khvalyn deposits.

Recently, new absolute dating of the deposits of the Khvalyn transgression has appeared (Arslanov et al., 2016; Semikolennykh et al., 2022). These datings make it possible to clarify the correlation of the cultural layers of the Yulovskaya site with the deposits of the Khvalyn transgression of the Caspian Sea.

2. Materials and methods

The Late Paleolithic site - Yulovskaya is located in the Salsky district of the Rostov region, 5 km south-east from Yulovsky, on the steep left bank of the Zapadny Manych River (GPS 46.75008915° N, 41.52271280° E).

The 7 m thick section studied is represented by lacustrine, subaquatic, and subaerial sediments (Lavrentyev et al., 2012). In the bottom-to-top section, three main lithological facies are distinguished:

1. the lower lithological facies are represented by coarse-layered lake loams with freshwater fauna of stagnant reservoirs, the apparent thickness is 3 m;
2. the middle lithological facies are represented by an alternation of thin-layered loams with a stagnophilic fauna, 1.5 m thick, and cultural layers 2 and 3 are confined to this lithological facies (Tsybriy, 2000);
3. the upper lithological facies are represented by subaerial loams with a total thickness of 2.5 m, in the middle part of the layer there is cultural layer 1 (Tsybriy, 2000).

In addition, individual coals were found in the excavation. Coal samples were taken for radiocarbon analysis (Amirkhanov and Praslov, 2001) from cultural

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layers 2 and 3:

Sample 1 is represented by individual coals, at a depth of 2.88-2.89 m, lithological facies 2. Radiocarbon age - 16650 ± 220 years ago (OxA - 9510). The calibrated date is 18674 years ago.

Sample 2-is represented by coals from the focal spot of the cultural layer 3, at a depth of 3.92 m – 3.96 m, lithological facies 2. Radiocarbon age- 17450 ± 400 years ago (OxA - 9511). The calibrated date is 20280 years ago.

Sample 3-is represented by coals from the focal spot 3 of the cultural layer 3, at a depth of 3.94-3.98 m, lithological facies 2. Radiocarbon age- 15290 ± 260 years ago (OxA - 9555). The calibrated date is 17205 years ago.

During the field work of the Paleohydrological Group, a horse bone was discovered at a depth of 4.9 meters in lithological facies 1. This bone was dated (Chepalyga et al., 2008). The radiocarbon age is 19540 ± 1470 years ago (LU-5852). The calibrated date is 25546 years ago.

The OxCal 4.4 program was used to calibrate the dates.

Palynology analysis was carried out for the upper 5 meters of the section of Shilova. Samples were taken after 5 cm in the middle part of the section, including the main horizons of the finds, and after 10 cm in the rest of the section; a total of 75 samples were studied (Lavrentyev et al., 2012).

According to Shilova, the samples at a depth of 4.9 m in the lake lithological facies 1. Belong to the Bryansk interstadial. Cultural layers 2 and 3, which are located in the subaqual lithological layer 2, belong to the LGM according to the polynological data. The cultural layer 1 is located in the lower part of the lithological layer 3 belongs to Dryas-1.

At the boundary between the lithological layer 2 and the lithological layer 3, the highest rate of re-deposited spores and pollen is recorded. There is also a lot of redeposited pollen in the lake sediments of the lithological layer 1.

According to V. V. Tsybriy (2000), the flint tools of the Yulovskaya site have an Upper Paleolithic appearance.

As for the absolute dating of the sea terraces of the Early Khvalyn transgression of the Caspian Sea. According to the authors of the study (Arslanov et al., 2016), the maximum stage (from 48 to 50 m) of the early Khvalyn transgression has not been dated. The transgressive stages of the early Khvalyn basin with sea levels 35-22 meters above sea level occurred approximately 16-14 thousand years ago.

As for the Khvalyn deposits in Manuch Depression, the nearest section is located 60 km upstream from the Late Paleolithic site of Yulovskaya, near the village of Manych-Balabinka. There is a dating of the early Khvalyn fauna 14300 ± 680 thousand years ago. MSU - 1491 (Svitoch and Yanina, 2001). The calibrated date is 17138 years ago.

164 kilometers downstream from the Late Paleolithic site of Yulovskaya, on the western tip of the island Left, OSL-datings were selected from the

Khvalyn deposits. According to the authors of the study (Semikolennykh et al., 2022), based on the results of OSL-dating, the time of functioning The early Khvalyn Strait in the Manych depression was determined in the range of 17.7–14.9 thousand years ago.

3. Results and discussion

The upper part of the lake sediments of the lithological layer 1 belongs to the Bryansk interstadial. As evidenced by the data of palynological analysis (Lavrentyev et al., 2012), as well as the dating of the horse bone 25546 years ago LU-5852 (Chepalyga et al., 2008). These are the deposits of the Gudilovsky Lake in its regressive stage.

Cultural layers 2 and 3 were formed in subaqual deposits of lithological layer 2, during LGM. This is confirmed by radiocarbon dating in the range of 17-20 thousand years ago (Amirkhanov and Praslov, 2001), and data from the polynological analysis (Lavrentyev et al., 2012). The territory of the Late Paleolithic site Yulovskaya was repeatedly flooded. Most likely, the Late Paleolithic site of Yulovskaya had a seasonal fishing and hunting character. The duration of habitation at the Late Paleolithic site of Yulovskaya is probably up to several months in the warm seasons of the year.

The Late Paleolithic site of Yulovskaya is located at the bottom of the Manych Valley. Consequently, it could have been flooded by the Manych Strait of the Early Khvalyn Sea. However, in the stratigraphic section of the Yulovskaya site there are no deposits of the Manych Strait of the Early Khvalyn Sea. Basically, the coastal cliffs of the Veselovsky reservoir, where the Late Paleolithic site of Yulovskaya was discovered, are represented by Gudilov deposits with freshwater malacofauna of standing reservoirs (the second above-floodplain terrace), and the first above-floodplain (Khvalynskaya) terrace is flooded by the reservoir (Lavrentyev and Chepalyga, 2011). Therefore, the flooding of the Late Paleolithic site of Yulovskaya by the Manych Strait of the Early Khvalyn Sea can be proved by indirect signs. Above the cultural layers 2 and 3, at the boundary between the lithological layer 2 and the lithological layer 3, the maximum peak of re-deposited spores and pollen is recorded. The pollen was probably transferred by the Manych Strait of the Early Khvalyn Sea. This hypothesis is confirmed by the dating of the Early Khvalyn fauna of the Manych Strait, which are in the range of 17.7–14.9 thousand years ago (Svitoch and Yanina, 2001; Semikolennykh et al., 2022).

Probably, the flooding of the territory of the Late Paleolithic site Yulovskaya by the Manych Strait of the Early Khvalyn Sea forced the ancient people to leave the Manych Valley. However, after that the Manych Strait ceased to exist. The ancient people returned to the territory of the Late Paleolithic site Yulovskaya (cultural layer 1). According to the data of the polynological analysis (Lavrentyev et al., 2012), the cultural layer 1 belongs to Dryas-1. This refers to the era of deglaciation of the Late Valdai glaciation

However, an additional research is required to confirm this hypothesis.

4. Conclusions

The published new datings of the Early Khvalyn deposits of the Manych Valley allowed us to clarify the stratigraphic position of the cultural layers of the Late Paleolithic site of Yulovskaya. And we also managed to confirm the previously published conclusions.

So, the formation of cultural layers 2 and 3 occurred in the LGM era, 17-20 thousand years ago. Then the Manych Strait of the Early Khvalyn Sea flooded the territory of the Late Paleolithic site Yulovskaya during the beginning of the deglaciation of the Late Valdai glaciation, 17-15 thousand years ago.

After the drainage of the Manych Valley, the ancient people returned to their former habitats (cultural layer 1).

Conflict of interest

The author declares no conflict of interest.

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Short communication

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Reconstruction of evolution of a shore lake (the White sea, NW, Russia) based on spore-pollen analysis

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ABSTRACT. The paleo-geographic conditions of sedimentation in a small nameless lake on the Karelian White Sea shore were reconstructed. The data obtained were used to trace the vegetation dynamics from the Boreal time. The time of transition from the marine to freshwater regime was determined.

Keywords: spore-and-pollen analysis, isolated basins method, shoreline migration, White Sea

1. Introduction

Bottom sediments from a small nameless lake (28.7 m a.s.l, N 66° 15' 34.4", E 33° 39' 22.2") on the Karelian White Sea shore near the Keret Town were studied. Changes in the position of the White Sea shoreline were assessed the isolated basins method (Hafsten, 1960; Donner et al., 1977). The method is based on the study of bottom sediments from continental freshwater bodies, where sedimentation conditions varied from marine to freshwater (transition zone). Spore-and-pollen analysis was performed with regard for halophyte pollen identified as an indicator of marine conditions. Such indicators were identified earlier by Lavrova et al. (2010), Shelekhova and Lavrova (2011) and are now studied by author.

2. Materials and methods

Sediments in small water bodies, located at different hypsometric levels were drilled. The results of spore-and-pollen analysis of one of the lakes are discussed in the paper. Samples for spore-and-pollen analysis were prepared using a standard procedure (Pyl'tsevoy analiz, 1950). Pollen was identified using manuals (Kupriyanova and Aleshina, 1972; 1978) and personal standard maps of figures and descriptions, as well as the pollen database <http://botany-collection.bio.msu.ru>.

3. Results and discussion

A spore-and-pollen diagram of bottom sediments, based on analytical results, was constructed. Seven pollen zones (PZ), consistent with modified Blytt-

Sernander's scheme were identified (Khotinsky, 1977). At a depth of 1110-931 cm, the samples contain no pollen grains. Woody tree pollen were dominates throughout the entire sequence (99%).

PZ1 *Pinus-Betula* sect.*Albae*- *Plantago* sp.-Polypodiaceae-Hepaticae (depth 931-870 cm). The palynozone is characterized maximum woody tree pollen values yielded mainly by *Pinus* (up to 90%) and *Betula* sect.*Albae* (up to 15%). The rare pollen grains of the obligate halophyte *Plantago maritima* were identified. The sporophyte dominate groups were presented by Polypodiaceae and Lycopodiaceae. Hepaticae spores, commonly occurring on non-formed soils, are scarce.

The obtained data show that the study area was covered by thinned pine forests, as indicated an abundance of Lycopodiaceae. The presence of pre-Quaternary sporomorphs suggests the rewashing of sediments at the marine stage of the lake. The sediments was most probably formed in the early Boreal Period.

PZ2 *Pinus-Ulmus-Alnus incana-Atriplex nudicaulis*-type *Aster* (depth 870-748 cm) differs from the previous palynozone as the presence of *Ulmus* and the persistence of maximum *Pinus* (up to 90%). *Alnus incana* increases to 1%. The pollen grains of the halophyte *Atriplex nudicaulis*, type *Aster* (presumably *Tripolium vulgare*) are scarce. Sporophytes abruptly become less abundant. The spectra of PZ2 likely formed in the Boreal time. The vegetation consisted of north-taiga forests (with a minor contribution of birch), which became more closed. Typical halophytes were present in the coastal zone.

PZ3 *Betula* sect.*Albae*-*Ulmus-Quercus robur-Tilia cordata*-Chenopodiaceae (depth 748-705 cm). The palynozone displays a decrease in *Pinus* pollen (to

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60%) and an increase in *Betula* sect. *Albae* pollen (up to 30%). *Quercus robur* and *Tilia cordata* pollen grains emerge in the spectrum. The sediments of PZ3 likely correspond to the early Atlantic Period.

PZ4 *Picea-Pinus-Ulmus-Corylus-Atriplex nudicaulis-Plantago* sp.-type *Aster* (depth 705-672 cm) differs from the previous one in sharply increased in *Picea* (up to 20%) and *Pinus* (up to 80%), as well as *Ulmus* and *Corylus* peaks. The presence of the pollen of the obligate halophytes *Atriplex nudicaulis* and *Plantago* sp., type *Aster* (presumably *Tripolium vulgare*) indicates the formation of marine sediments. Sediments in the palinozone formed in the mid-Atlantic Period.

PZ5 *Picea* (depth 672-630 cm) the percentage of *Picea* increased (up to 30%), while that of *Pinus* pollen decreases to 50%. Coniferous plant stomata were encountered in the spectra for the first time. *Typha latifolia* and *Utricularia* pollen of the aquatic group was observed. The spore-and-pollen spectra of this time interval display the pollen grains of halophytes and representatives of coastal-aquatic freshwater vegetation. The zone marking a transition from marine to freshwater conditions was thus identified. The eggs of tardigrades, who prefer freshwater environments, are present. Sediments in this palinozone formed at the final stage of the Atlantic. This evidence is supported by two radiocarbon age dates (depth 666-661 cm was 5610 ± 200 ^{14}C yr., and 661-656 cm was 5270 ± 110 ^{14}C yr.). Mid-taiga spruce forests mixed with birch were spread on the area.

PZ6 *Pinus-Picea-Ericales* (depth 630-590 cm) was identified by an abruptly increased abundance of *Pinus* pollen (up to 85%) and a decrease in *Picea* pollen (to 10%). *Ericales* pollen in the spectrum increases.

PZ7 *Pinus-Pediastrum* (depth 590-550 cm), the woody plant group *Pinus* was dominate (up to 90%), while the percentage of *Betula* sect. *Albae* decreased to 5%. Colonies of the alga *Pediastrum* emerged in the spectra and is indicative of freshwater conditions. Sediments in palinozones PZ6-PZ7 formed in the Late Holocene. The spruce-pine forests cover was dominated.

4. Conclusions

A long time during the Boreal - Late Atlantic Periods (depth 931- 660 cm) the study area was covered by the sea. Since the Mid-Atlantic Period, the sea boundary began retreat and the sea gradually began to desalinate (depth 660-630 cm). In the Late Atlantic

Period, the reservoir separated completely and began to evolve as an independent freshwater body. The plant cover in the Boreal consisted of north-taiga birch-pine forests mixed with birch. The intensive paludification of the study area began at the final stages of the Holocene.

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Conflict of interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Present sedimentation in the volcanic lakes of the Kurile-Kamchatka region (Russia) as a basis for paleoreconstructions

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ABSTRACT. The results of modern processes observations of the sedimentation in the volcanic lakes of the region are summarized with the use of material from other regions of the world. The available data on the drained volcanic lakes deposits, Uzon-Geysernaya caldera as example, was analysed. The main sources of material (volcanic and post-volcanic activity, gravitational displacements on slopes, and erosion-denudation processes) and the mechanisms of its entry into volcanic lakes, as well as the features of the subsequent deposits transformation as a result of hydrothermal, seismic, and volcano-tectonic activity, are identified. The results of the studies carried out allow us to conclude that the volcanic lakes deposits are complexly constructed polyfacial complexes with alternating fine-grained lacustrine and lacustrine-swamp deposits with pyroclastic horizons and interlayers of untreated or poorly processed coarse clastic material coming as a result of volcano-tectonic activity, gravitational and erosion processes. The irregularity of horizons along strike is typical; and is characterized by the large-scale sediments deformation under the influence of seismic activity, growth of effusive and extrusive domes, phreatic explosions, etc. Hydrothermal activity contributes to the weathering and cementation of the lake sediments. Lava outpourings and the high-temperature pyroclastic flows provokes sintering of contacting horizons sediments.

Keywords: level fluctuations, volcanic activity, gravitational processes, pyroclastic deposits, gas hydrotherms

1. Introduction

The volcanic - crater and caldera - lakes of the Kuril-Kamchatka region have not been studied extensively. Due to their inaccessibility there were very few special studies of their sedimentation features (Kremenetskaya, 1977; Kraevaya et al., 1979; Egorova, 1993), in contrast to the coastal-marine (lagoon and deltaic) lakes of the region, which are considered in sufficient detail in the numerous works Far Eastern researchers led by A.V. Lozhkin and N.G. Razzhigaeva. Due to the specifics of the volcanic lakes functioning there is often a certain difficulty in carrying out paleoreconstructions and interpreting the mechanisms and conditions of sedimentation. The purpose of this work is to generalize and analyze the results of modern geological and geomorphological processes observations within the basins of predominantly caldera lakes in the Kurile-Kamchatka region, the nature of volcanic and post-volcanic activity and the sedimentation features, to determine the main sources of material entering the basins, its characteristics, the nature of distribution and diagenesis features.

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2. Materials and methods

The modern geomorphological processes in the Golovnin (Kunashir Island), Ksudach, Kuril'skoe Lake, Uzon-Geysernaya (Kamchatka) calderas were studied by the author during the field observations in 2015-2021, also the interpretation of high-resolution images was done. The structural features of a number of lake's basins under the consideration were established by D.N. Kozlov earlier according to the detailed echolocation survey data (Kozlov, 2015; Kozlov et al., 2019; and others). The constructed bathymetric maps analysis made it possible to conclude that the caldera lakes basins in the region are often complicated by the volcanic structures, amongst which the extrusive and effusive domes and the explosive funnels of various sizes are distinguished (Kozlov et al., 2019). The sources of water and the dissolved mineral components in the lakes are not only atmospheric precipitation and surface runoff, but also the gas-hydrothermal vents, the activity of which depends on the degassing process of the nearest magma chamber. As a result, in many lakes, water has a high mineralization, and its temperature

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is increased compared to non-volcanic reservoirs. Traces of hydrothermal activity are recorded both on the lakes shores and in the deep parts of basins; often, gas hydrotherm outlets are directly related to the revealed underwater volcanic structures. An important distinguishing feature of many volcanic lakes is the periodic rapid changes in their main characteristics (shape, volume, temperature, water chemical composition etc.) over a wide range, which is due to the peculiarities of the nearby volcanic centers functioning (Kozlov and Lebedeva, 2022).

3. Results

The following sources and mechanisms of material supply to the lake basins have been established.

3.1. Volcanic activity is the main source of volcanic lakes deposits. First of all, these are various types of volcanic cones eruption nearby or inside the lakes. Lava outpourings (a) with the formation of lava flows, as well as the explosive eruptions (b), not only with the release of a large volume of pyroclastic (c), but also with the partial destruction of the volcano cone (d), stand out among them. Such phenomena leads to the active filling of calderas with pyroclastics, the large-block material inflow into the lakes, and sometimes to temporary blocking of the water outflow. Abundant ash falls and the formation of intracaldera pyroclastic flows (e) lead to the filling of lake basins with finer tuff material.

An important influence is exerted by the volcanic structures growth - effusive and extrusive cones (f) within lakes and in their immediate vicinity. This process occurs quite quickly: an average rate of an underwater cone growth in the lake Shtyubel (Ksudach caldera) ranged from 1 to 1.6 m/year (Kozlov and Lebedeva, 2022). In the lake Karymsky (Academy of Sciences caldera, Kamchatka), a tuff cone with a crater about 600 m in diameter and up to 60 m deep formed just in a few days - directly during the eruption in January 1996 (Muravyev et al., 1997).

During the grow of these volcanic structures, not only the lake bottom morphology changes: a single lake can break up into several ones, or acquire a specific shape (rings or horseshoes), occupying the lowest areas. At the same time, sedimentation conditions also change: young lacustrine deposits can be deformed or raise above the lake level, and the intracaldera river network is forced to restructure according to changes in the surface slopes, and the alluvial and proluvial accumulation zones also change accordingly (Lebedeva, 2017a; 2017b). Due to high temperatures, sintering of contacting lacustrine deposits can occur, as it is in the formation of lava and pyroclastic flows, as a result of which the deposits structure and mechanical properties change fundamentally. The extrusions growth in the adjacent territory may be accompanied by the formation of their marginal parts collapses, the entry of coarse clastic material into the lake, and even the blocking river outflow from it, as happened in the Kuril'skoe Lake caldera (Ponomareva et al., 2006).

3.2. Postvolcanic gas-hydrothermal activity.

Gas-hydrothermal activity is often observed in the basins and within the volcanic lakes coastal zone, which persists even when volcanic activity subsides. The treatment with highly mineralized thermal waters leads to the material deposited in the lakes weathering, and in some cases to the lake sediments cementation. It is possible to form specific underwater accumulative forms - spiers and towers - directly at the gas hydrotherms outlets, and when the level of lakes fluctuates, subaerial accumulative hydrothermal forms - sinter terraces and geyserite cones - can also be flooded. The traces of hydrothermal explosions in the form of a specific breccia deposits can be found periodically.

3.3. Gravitational displacements on the basins slopes. Entry of the significant volumes of the clastic material into the lake baths is also facilitated by various scales gravitational displacements on the basins slopes. These include both debris avalanches as a result of the nearby volcanic cones destruction (Uzon-Geysernaya caldera), as well as small collapses and the landslides. Results of multi-temporal images analysis of the Mal. Semyachik volcano's crater (Kamchatka) showed that the total amount of the material that entered the lake Zelenoe located there from the slopes over 44 years amounted to 1.5 million m³ (Svirid et al., 2013), or about 34 thousand m³/year.

3.4. Erosion-denudation activity includes active removal of the pyroclastic material by rivers into the lakes from the calderas walls, as well as the lahars descends both along valleys and from the slopes. Thus, in the Ksudach caldera, there was one of the most intensive relief formation processes during 25 years of observations the growth of alluvial fans at the river mouths (Kharchenko et al., 2020).

4. Discussion and conclusions

In modern volcanic lakes, there is a rapid filling of their basins with pyroclastic material carried from the sides and carried out by intracaldera streams, as well as deposits of pyroclastic flows, lahars and debris avalanches, volcanic bombs and lava flows. Thus, volcanic lakes accumulate material of various sources, morphometric characteristics, and composition: from lava layers, boulders up to 5–7 m in diameter to poorly processed and sorted mudflow material, as well as pumice pebbles rounded during transportation by water flows, to large volumes of finely dispersed pyroclastic. As a result, lake sediments are complexly built polyfacial complexes with alternating thin cemented tuff with layers of poorly processed coarse clastic material coming as a result of volcanic and volcano-tectonic activity, gravitational and erosion processes. Lacustrine sediments are often deformed as a result of seismic activity, the effusive and extrusive domes growth, and phreatic explosions. Hydrothermal activity leads to sediment cementation. The underwater cones growth, lava outpourings and high-temperature pyroclastic flows provokes to contacting horizons sediments cementation.

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Conflict of interest

The author declares no conflicts of interest.

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Theoretical aspects in the study of sources and origin of modern and buried organic matter in biogenic deposits from salt lakes of the arid zone (Western Siberia, Russia)

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ABSTRACT. We present the approach and methods of research of biogenic sedimentation in lakes of arid zone of Eurasia, data from Western Siberia.**Keywords:** bottom sediments, geochemistry, saline lake, Holocene, paleoclimate

1. Biogenic deposits of lakes from different climatic zones of Western Siberia

Terminal lakes play an important role in deposition of organic matter (OM) in continental environment. The sediment origin and sedimentation intensity are depended many factors, including the climatic characteristics of the region. Content of OM in lakes located in high latitude subarctic climatic zone and high altitude mountains as usual is not high, while they can accumulate diatomite – inorganic biogenic sediment, presented in lakes of Kola Peninsula, Karelia, in Lakes Baikal and Sevan. Calcareous lake deposits may also be biogenic. Limestone sediments are formed from calcite and aragonite ostracod shells in the brackish-water Issyk-Kul Lake (Rasskazov et al., 2021). Biogenic calcite (CaCO_3) also forms in some submerged macrophytes (*Potamogeton*) and *Chara* algae.

The most intensive accumulation of OM occurs in lakes of the boreal humid climatic zone.

Living organisms in these lakes have a high assimilation potential to produce biomass during photosynthesis. However, in order for a group of producer organisms to participate meaningfully in the formation of nutrient sediments must be: i) conditions for normal development in the lake (the value of primary production); ii) remain in lake sediments (Korde, 1960).

Bio-chemic deposits were accumulated in saline and hyperhaline lakes at the arid climate zone with high rate of evaporation and salt precipitation process. Salinity of high-mineralized lake controls abundance and species diversity of halophile organisms, indirectly influences the primary production. According to our

data (Leonova et al., 2006), the total salt content in the studied salt lakes of the arid zone of Western Siberia widely varied: Lake Kulundinskoye - 94, Lake Bolshoye Yarovoye -172, and Lake Maloye Yarovoye - 262 g/l. The sources of OM in modern biocenoses in these lakes are dominant planktonic halophilic species of cyanobacteria (*Chlorogloea sarcinoides* (Elenk.) Troitzk.; *Lingbia kassinskajae* Elenk.; *L. lutea* (Ag.) Jom.), green algae (*Dunaliella salina* Kütz.), and filamentous green algae (*Cladophora fracta* (Vahl.) Kütz.), which in mass reproduction cause water-weeding. The zooplankton in the hyperhaline lakes of the Kulunda steppe is represented by the brine shrimp (*Artemia salina* L.).

The primary production of OM is a result of reproduction of autotrophic photosynthetic phytoplankton, periphyton and macrophyton. The contribution of each group to the primary production depends on the degree of their development in lake biocenosis. Lake ecosystems are classified by the predominant OM from macrophytic and phytoplanktonic (Pokrovskaya et al., 1983).

The gross primary production of phytoplankton in lakes of the Kulunda steppe was determined by the light-and-dark-bottle method in oxygen modification (Vinberg, 1960). The method attracts by the simplicity of the experimental procedure. In the background bottles, the initial concentration of oxygen is measured. Then after daily exposure, oxygen concentrations in «light» bottles (oxygen formed during phytoplankton photosynthesis) and in «dark» bottles (oxygen used for phytoplankton respiration) are measured. The intensity of production and destruction processes in the water is determined by the difference of oxygen concentrations in «light» and «dark» bottles. The maximum value of

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phytoplankton photosynthesis (the value of primary production of organic carbon) estimated in hyper-saline Lake Kulundinskoye is 528 g C/m² per day; it is much lower in Lake Bolshoye Yarovoye - 52 g C/m² per day. It is known that the efficiency of photosynthesis in lakes reflects the ratio of assimilation (OM production) and dissimilation (OM destruction). In Lake Kulundinskoye production processes more than 2 times dominate over the destruction processes, indicating OM accumulation. In Lake Bolshoye Yarovoye, balance of primary production is negative, that is, destruction of OM dominates over production. As for brain shrimp, its biomass in the largest *Artemia* harvesting Russian Lake Kulundinskoye is in the range of 2,33–9,05 g/m³, in the Bolshoye Yarovoye — 5,33–38,2 g/m³ (Leonova et al., 2007).

2. An approach to determine sources and origin of modern and buried organic matter

The organic material buried in lake sediments reflects to the historical record of sediment conditions. The identification of sources and genesis of buried OM in lake sediments is an extremely complex task that requires an integrated approach involving special methods of analysis and organo-geochemical criteria, implicitly confirming the genetic relationship of the buried OM to the original autochthonous and allochthonous OM (Leonova et al., 2019). The direct method of layer-by-layer quantification of organisms (integrated biological analysis - biostratification) is considered to be the priority and the most reliable (Korde, 1960). The integrated biological analysis provides an indication of the sources of the buried OM and helps to decipher the sedimentation conditions in the lakes.

Together with direct biostratification method bio-geochemical indication for hydrocarbon biomarkers (normal aliphatic hydrocarbons - n-alkanes) is used, which according to (Peters et al., 2008; Melenevsky et al., 2015), are defined as complex molecular «prints» of living organisms formed from their biochemical components. Molecular-mass distribution of n-alkanes is individual for different sources of OM. For example, long-chain odd n-alkanes with maximums C₂₃, C₂₅, C₂₇, C₂₉, C₃₁, C₃₃, C₃₅, contained in wax coatings of plants, indicate the dominant contribution of higher on-land vegetation and can serve as biomarkers for modern and ancient terrigenous OM. Low-molecular homologues of C₁₂-C₁₉ hydrocarbons are characteristic of planktonogenic OM. Bacteria typically have an n-alkane distribution in the C₁₅-C₂₈ range. One of the most important relict hydrocarbons that retain their biochemical structure are the hopane hydrocarbons. Biohopans - products of the diagenetic chain of transformations of bacteriophanopolyol, dominate in immature OM of modern lake sediments. Hopanoid biosynthesis occurs in both aerobic and anaerobic bacteria, as well as in some species of sulfate reducers and metanophores (Blumenberg et al., 2006).

The ratio of organic carbon to organic nitrogen C_{org}/N_{org} gives an approximate idea of the sources and genesis of modern and fossilized lacustrine OM (due to

the uncertainty of the degree of transformation of OM in the diagenesis). It reflects differences in the biochemical composition of the primary OM producers. The higher terrestrial vegetation is nitrogen poor and has a high C/N value 20-40, for diatomic phytoplankton this ratio is 5.5-10, the lowest C/N value 2.8-4.5 is characteristic of zooplankton (Vinogradov, 2001).

Thus, reliable identification of sources (primary bio-producers) of modern and fossilized organic matter in fresh, brackish, saline and hyper-saline lakes requires the use of a set of bio-geochemical criteria: 1) Biostratification; 2) Composition of normal aliphatic hydrocarbons (n-alkanes); and 3) C_{org}/N_{org} ration (Leonova et al., 2019).

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Conflict of interest

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Short communication

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Monitoring of the polygonal reservoir of the Kytalyk reserve (Indigirka river)

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ABSTRACT. Diatom analysis is one of the methods of paleolimnological research, with the help of which it is possible to determine the state and development of aquatic ecosystems in the past and present. Assessment of the current state of reservoirs is of great importance in paleolimnology, it will allow to obtain results about temperature regime, mineralization, pH environment and water quality. The research area is a region with a lot of small polygonal reservoirs that react quickly enough to external environmental changes that are formed during the cracking of re-vein ice and may form large reservoirs in the future. In this work, the IP-1 monitoring reservoir of the Kytalyk locality was studied for 10 days (every three days) during the expedition work carried out in 2011 using standard methods and a set of field equipment. The material of the study was phytoplankton samples, as a result of which the taxonomic composition of the diatom flora was investigated and the water quality of the Kytalyk monitoring site located in the basin of the Berelyakh river, the left tributary of the Indigirka, was determined.

Keywords: polygonal reservoirs, diatoms, saprobity, Indigirka, Yakutia, Arctic

1. Introduction

Diatoms are often used as indicators in biogeographic studies of water bodies due to the fact that this group of algae is distinguished by the presence of a kind of “shell” consisting of silicon dioxide in cells (Belyakova et al., 2006). Diatoms in aquatic ecosystems dominate other microscopic algae all year round. They are abundant in plankton, periphyton and benthos. The reservoir under study lies within a typical tundra, is characterized by a very shallow depth of 0.5 m, the shape of the mirror is close to rounded (elongation coefficient = 1.6). Water is ultra-fresh (with a total mineralization of 15 mg/l), pH av. 6.3, total hardness av. 0.4.

The aim of the work is to assess the condition of the monitoring reservoir located in the basin of the Indigirka river with the use of diatom indicator species. The results of this study can be used as data on the current state of natural reservoirs for the purposes of background environmental monitoring, as well as for information support of stakeholders in the implementation of economic and water management measures in the arctic region of the Republic of Sakha (Yakutia).

2. Materials and methods

The material of the study is diatom complexes of the selected IP-1 monitoring reservoir located at the upper level of the alas of the Kytalyk resource reserve. The territory of the studied reservoir located on the Nizhneindigirsky lake-thermokarst province of continuous distribution of permafrost rocks within a typical subzone of the tundra zone of Northeastern Siberia (Nekrasov and Melnikov, 1989). The actual material was collected during field expedition work in 2011 using standard sampling and material processing methods described in the authors' works (Gorodnichev et al., 2015). Diatom analysis of phytoplankton samples was performed according to the generally accepted quantitative methodology (Obshchiye zakonomernosti..., 1986).

To assess the current state, the Pantle-Bukka method was used in the modification of Sládeček (Sládeček, 1973; 1986), the affiliation of diatoms-indicators to a particular zone of saprobity was determined by the lists of saprobic organisms (Makrushin, 1974; Unifitsirovannyye metody..., 1976; 1977; Denus, 1991; Barinova and Medvedeva, 1996).

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HOBO loggers were used to measure the physical parameters of the reservoir. Phytoplankton collection using a mesh (diameter 5 microns) and measurements of water parameters were carried out simultaneously every 3-4 days.

3. Results and discussion

According to the results of the study, 41 species (including 1 variety) of diatoms belonging to 16 genera, 13 families and 2 classes of the Bacillariophyta division were found in the surface sediments of the studied reservoirs, as described earlier. Of these, the most numerous class of Bacillariophyceae includes 39 species out of 41 (which is 95% of the entire flora), the class Coscinodiscophyceae includes only one genus *Aulacoseira*, represented by two species. The largest number of species has been recorded in the genus *Eunotia* of 14 species and varieties, which is 34.1% of the total number of species. Then the genus *Neidium* and *Pinnularia* are represented by 4 species, the genera *Gomphonema* and *Stauroneis* are represented by 3 species. The remaining genera are represented by two or single species, which is 34.1%. The list of mass forms (more than 5%), which was identified using a percentage of the total number, has 11 species, including dominant (more than 10%) 6 species, subdominants (more than 5%) 5 species. Among them, it is worth highlighting the species *Eunotia bilunaris* and *Tabellaria flocculosa*, which are absolute dominants in all the samples studied, ranging from 8.5% to 23% and from 15 to 30%, respectively, with the maximum values of *Eunotia bilunaris* at points IP1-2, IP1-4 and IP1-7 and *Tabellaria flocculosa* in IP1 and IP1-8. The species *Pinnularia brevicostata* (27% in IP1-6), *Stauroneis phoenicenteron* (16% in IP1-6), *Eunotia paludosa* (11%

in IP1-5), *Eunotia septentrionalis* (15% in IP1-9) are dominant and subdominant in most of the samples studied. By number (by the number of valves in 1 liter of water), the species *Tabellaria flocculosa* absolutely dominates in the studied reservoirs, which is found in all 10 samples studied.

An analysis of the comparison of the ratios between the concentration of diatom flaps in phytoplankton with the physical parameters of water (water temperature, pH, electrical conductivity and oxygen concentration) of a model reservoir, measured in the field using loggers, is shown in figure 1. Judging by the graphs, all the measured indicators are fairly evenly correlated with each other. It can be seen that the value of the concentration of the flaps reacts relatively well to changes in water temperature – with a decrease in the temperature index, the number of registered flaps increases. This may indicate that mainly cold-water species live in polygonal reservoirs of the Arctic, at a water temperature of 7.2 °C (one of the minimum values for the entire sample), the concentration of flaps reached 50.9 million/l, while at the highest temperature up to 19 °C, the concentration of flaps was equal to 2.8 and 1.8 million/l.

In order to determine the water quality of the studied lakes, saprobity indices were calculated using 41 types of diatoms-saprobity indicators. Of these, 9 species characterize the oligosaprobic zone, 5 – beta-mesosaprobic, 4 – xenosaprobic and 1 – alpha-mesosaprobic. Calculated indices of saprobity by diatoms for the studied lakes range from 0.6 to 1.1, i.e. in terms of pollution they belong to class I “very clean” and class II water quality “clean” (Fig. 2). At the same time, a relatively high saprobity index was noted on 09.08, when all measured water parameters were high.

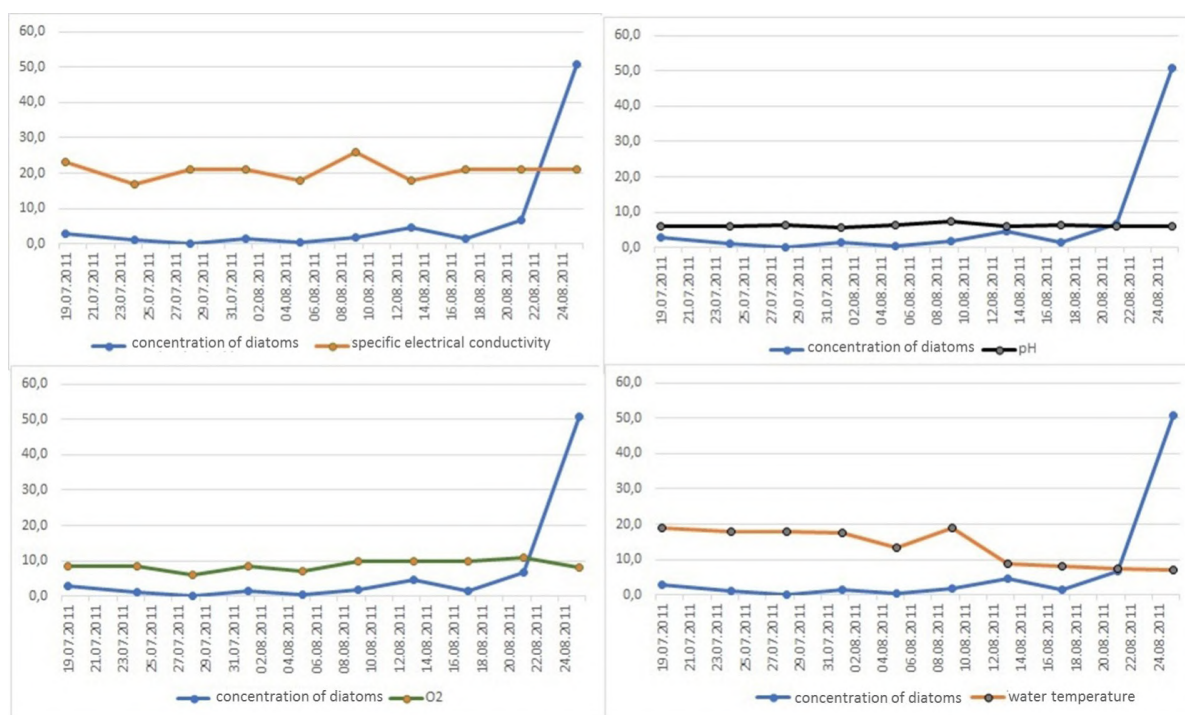


Fig.1. The ratio of physical parameters of water and concentrations of diatoms in the phytoplankton of the model reservoir.

4. Conclusions

Thus, the paper describes the taxonomic composition of the diatom flora, to determine the water quality of reservoirs, a saprobiological analysis of surface waters was carried out, which occupies one of the main places among the biological methods of surface water analysis. Since diatoms are found almost everywhere where there is water, and always prevail in biomass, they are good indicator species.

According to the results of the research, the following conclusions can be drawn:

- the diatom flora of the studied lakes, which represent an important group of environmental indicators, includes 41 species (including 1 variety) belonging to 16 genera, 13 families, 8 orders and 2 classes of Coscinodiscophyceae and Bacillariophyceae;
- small thermokarst reservoirs are represented by fairly young reservoirs of waterlogged (due to low evaporation) territories. The main source of their nutrition is the low mineralized waters of the ground ice. Excess of the input part of the component of the water balance contributes to maintaining low mineralization;
- according to the degree of organic load of water, the reservoir belongs to the category of very clean and pure (I and II class of water quality);
- the concentration of diatom flaps (million/g) is affected by the water temperature, in polygonal water reservoirs, cold-loving species prefer low water temperatures prevail.

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Conflict of interest

The authors declare no conflict of interest.

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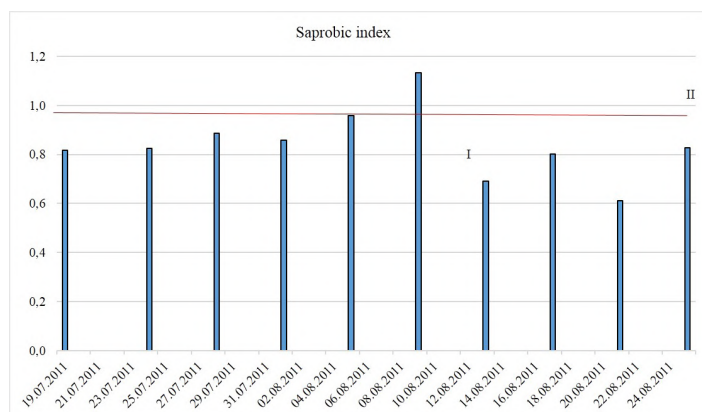


Fig.2. Integral saprobity index and the degree of contamination of the model reservoir water.

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On the marine limit at the Kandalaksha Coast, the White Sea: new data from Lake Kanozero, a huge isolation basin in the middle course of the River Umba

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ABSTRACT. The study revealed the evidence for the marine waters penetration into the basin of Lake Kanozero (SW part of the Kola Peninsula) in the Late Glacial. While previous studies found no signal of marine transgression above ca. 41 m a.s.l., our results suggest that the local marine limit exceeded ca. 53 m a.s.l., and the sea ingressed as far inland as ca. 50 km from the present White Sea coast.

Keywords: relative sea level changes, diatoms, isolation basins, Late Glacial marine transgression

1. Introduction

Lake Kanozero, located in the SW part of the Kola Peninsula (Fig. 1A) is famous by the ancient stone-carvings abundant on its islands. The evidence of the early human presence on its shores has raised interest to the lake's paleoenvironments. The multi-proxi study of the upper part of the sediment sequence from Lake Kanozero covering the end of the Late Glacial and the Holocene has been performed and published elsewhere (Sapelko et al., 2022). The lowermost sediments that archive the record of the earliest stage of the lake's evolution, however, remained beyond the scope of

that publication, and are in focus of the present study. Here we discuss the results of the diatom analysis of the lowermost part of the sediment sequence aimed at reconstructing the initial stage of the development of Lake Kanozero.

2. Materials and methods

Lake Kanozero (67°3'33" N, 34°6'12" E, 52.7 m a.s.l.) is a large basin (area 84.3 km², water volume 0.27 km³, mean depth 3.2 m, max depth 10.6 m (Resursy...,

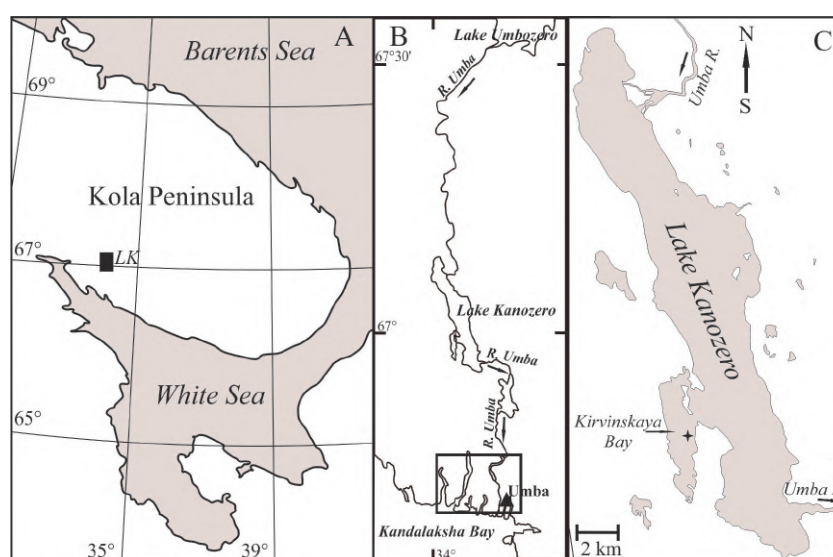


Fig.1. Location map of the study site. LK on 1A stands for Lake Kanozero; black frame on 1B indicates the area where previous isolation basin studies (Kolka et al., 2013) were performed; star on 1C indicates the sampling point.

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1970)) in the middle course of the River Umba (Fig. 1B). As the River Umba inflows to and outflows from the lake, it can be also considered a large spill on the river. The lake basin is NW-SE-oriented and has an elongated shape. The distance from its SE end to the White Sea coast is ca. 28 km.

The 3.4 m-long sediment core was retrieved from the Kirvinskaya Bay, a sheltered bay in the SW part of Lake Kanozero (Fig. 1C). Two main lithological units were described, 1) ca. 1-m thick light bluish-gray clay gradually passing into 2) 2.4-m thick greenish-brown and brown gyttja. Samples for the diatom analysis were pretreated following the standard procedure (Davydova, 1985).

3. Results and discussion

In the lower 0.4 m of the clay, resting spores of brackish and brackish-marine *Chaetoceros* spp. are the most abundant (to 60%), while other common taxa include brackish-marine *Cocconeis scutellum*, brackish *Fragilaria fasciculata* and *Rhoicosphenia baltica*, halophilous *Achnanthes haukiana*, and salinity-indifferent *Epithemia adnata* and *Rhopalodia gibba*. The proportions of the planktonic and benthic taxa fluctuate. The composition of the diatom assemblages suggests higher-salinity environments such as in a coastal zone of a freshened marine bay (Table).

Upwards, there is a narrow zone where brackish-marine *Chaetoceros* spp. rapidly decline in abundance, while brackish *Mastogloia smithii* and halophilous *Epithemia sorex* and salinity-indifferent small-celled *Fragilariaceae* increase. Both the proportion of benthic species and diatom concentration rapidly increase as well. The diatom record indicates decreasing salinity and depth of the basin as a result of decreased marine influence (Table). Preliminary, this transition was pollen-dated to late Allerød. The transition to freshwater conditions, however, has left no visually recognized signature in the sediment composition. Neither is could be observed in LOI values suggesting that sedimentation environments did not change accordingly.

In the upper ca. 0.55 m of the clay, brackish, brackish-marine, halophilous taxa disappear from the diatom record, and freshwater salinity-indifferent species became dominating. Benthic diatoms prevail (86-99%) with abundant small-celled *Fragilariaceae* (40-60%). *Amphora pediculus*, *Cocconeis neodiminuta*, *Navicula aboensis* and *Navicula jaernefeltii* are among the common taxa (Table). *Aulacoseira ambigua*, typical of lacustrine plankton is also sporadically found. The composition of the diatom assemblages points to sedimentation in the shallow-water part of a large cold-water low-productivity lake. The uppermost part of the clay unit was pollen-dated to Younger Dryas (Sapelko et al., 2022).

The diatom analysis of the uppermost part of the clay and the overlaying gyttja revealed the conditions of the shallow-water zone of a large cold-water oligotrophic basin that turned more productive with the Early Holocene climate amelioration. Subsequent water-level lowering and weakening of the water exchange between the Kirvinskaya bay and the main lake basin were also reconstructed (Sapelko et al., 2022).

The present study of the lowermost part of the sediment sequence from the Kirvinskaya Bay of Lake Kanozero revealed the evidence for the late-glacial marine transgression and subsequent isolation from the sea (Table). Thus 84.3 km²-large Lake Kanozero represents an isolation basin with marine-lacustrine transition recorded in its sediments. Similarly, the transition from marine to freshwater environments was previously observed in the sediment and diatom records from the small semi-enclosed bay of Lake Kolvitskoye, ca. 20 km west of our study site (Ludikova and Grekov, 2017), suggesting that this large inland lake can be considered an isolation basin as well.

The lack of the isolation signal in the sediment composition in Lake Kanozero indicates that minerogenic allochthonous sedimentation proceeded in the lacustrine environments. Apparently, severe climate of the Late Glacial resulted in low productivity of the lake ecosystem.

Table. Main diatom species and reconstructed environments in Lake Kanozero

Lithology	LOI, %	Age, cal. BP	Main diatom taxa	Salinity environment
brown gyttja	39-41	9200	<i>Achnanthes minutissima</i> , <i>Anomeoneis vitrea</i> , <i>A. brachysira</i> et var. <i>zellensis</i> , <i>Navicula radiosa</i> , <i>Cymbella</i> spp., <i>Pinnularia</i> spp., <i>Cyclotella</i> spp.	Freshwater
greenish-brown gyttja	4,5-30		<i>Fragilaria exigua</i> , <i>Staurosira construens</i> , <i>S. venter</i> , <i>Staurosirella lapponica</i> , <i>S. pinnata</i> , <i>Aulacoseira ambigua</i> , <i>A. valida</i>	
light bluish-gray clay	1,9-3,2		<i>Fragilaria exigua</i> , <i>Staurosira venter</i> , <i>Staurosirella pinnata</i> , <i>Cocconeis neodiminuta</i> , <i>Navicula aboensis</i> , <i>N. jaernefeltii</i> , <i>Aulacoseira ambigua</i>	
			<i>Staurosira venter</i> , <i>Mastogloia smithii</i> , <i>Epithemia sorex</i>	Transitional
			<i>Chaetoceros</i> spp., <i>Cocconeis scutellum</i> , <i>Fragilaria fasciculata</i> , <i>Achnanthes haukiana</i> , <i>Epithemia adnata</i> , <i>Rhopalodia gibba</i>	Brackish-water

The general pattern of relative sea level (RSL) change in the coastal regions of the western part of the White Sea suggests the sea-level rise after deglaciation, followed by an early Holocene highstand and subsequent RSL fall (Baranskaya et al., 2018). Previous studies of the coastal isolation basins near Umba village, south of Lake Kanozero (Fig. 1B), revealed that the marine transgression started in the area ca. 13200 cal. BP, and lasted during the Younger Dryas till the onset of the Holocene (Kolka et al., 2013; Kolka and Korsakova, 2017). The uppermost basin where the late-glacial marine transgression was recorded is located slightly above 41 m a.s.l. It was suggested that the lake depressions located at higher elevations remained blocked by dead ice until the late Preboreal (Kolka et al., 2013). However the time of the transgression maximum and the marine limit in the area remained undetermined. Starting from the late Preboreal, the regressive trend prevailed, and ca. 10300 cal. BP the RSL dropped below ca. 41 m (Kolka et al., 2013).

Our results demonstrate that in the Late Glacial, marine waters entered the basin of Lake Kanozero, and thus the level of the marine transgression exceeded 52.7 m a.s.l., i.e. the present elevation of the lake. The marine waters penetrated as far inland along the River Umba as up to the NW end of the lake, at least, which is ca. 50 km from the present White Sea coast. Subsequently, the marine basin retreated from the depression of Lake Kanozero that resulted in the transition from brackish-to freshwater environments. Previous diatom studies also demonstrated that the lake remained freshwater during the Holocene (as summarized in Table).

4. Conclusions

1) Lake Kanozero can be considered an isolation basin as its sedimentary archive records the transition from marine to lacustrine environments at the earliest stage of its evolution. 2) The level of the late-glacial marine transgression in the area exceeded ca. 53 m a.s.l., and the sea ingressed as far inland as ca. 50 km from the present White Sea coast. 3) The signal of the isolation from the sea was not recognized in the sediment composition indicating no corresponding change in the sedimentation environment.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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The evolution of the ecosystem of the Unitskaya Bay (Lake Onega) in the late- and postglacial times as inferred from the siliceous microalgae study

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ABSTRACT. The study of the siliceous microalgae (diatoms and chrysophytes) enabled reconstructing the evolution of the ecosystem of the Unitskaya Bay, the northern bay of Lake Onega. Changes in the composition of diatom assemblages, floristic diversity and abundances of siliceous microalgae indicated past productivity changes, as well as shifts in duration of hydrological and biological seasons.

Keywords: diatoms, chrysophyte cysts, lake sediments, paleoreconstructions, Late Glacial, Holocene

1. Introduction

Lake Onega is a large and deep cold-water basin in NW Russia (water area 9720 km², water volume 295 km³, max depth 120 m), the second largest lake in Europe following Lake Ladoga. Lake Onega appeared as the last Scandinavian Ice Sheet retreated from its basin, and subsequently evolved under the influence of climate changes, water-level fluctuations, glacioisostatic uplift and neotectonic movements.

Previously, main changes in the diatom assemblages have been described in five sediment cores collected from different parts of Lake Onega (Davydova, 1976). An attempt to relate these changes to the regional environmental shifts has been also made. The present study is aimed at reconstructing the evolution of the Unitskaya Bay, northern part of Lake Onega, in the Late Glacial and Holocene using siliceous microalgae (diatoms and chrysophytes). We also made an effort to interpret shifts in the diatom assemblages composition and abundances of the siliceous microalgae in the context of changing duration of hydrological and biological seasons in the past.

2. Materials and methods

The Unitskaya Bay is a long and narrow shallow-water bay (max. width ca. 4,5 km, length ca. 45 km, prevailing depths 10-20 m) deeply incised into the

northern Onega coast (Fig. 1A). The Vegorukskiy Peninsula and Mizh Island in the mouth of the Unitskaya Bay hinder its connection to the open-water part of Lake Onega.

The diatom analysis was performed for ca. 240 cm-long sediment sequence retrieved from 25 m depth in the SE part of the Unitskaya Bay (N 62°19,863, E 34°46,747, Fig. 1B). The sequence consists of three lithological units: 1) varved clay, 2) homogenous clay,

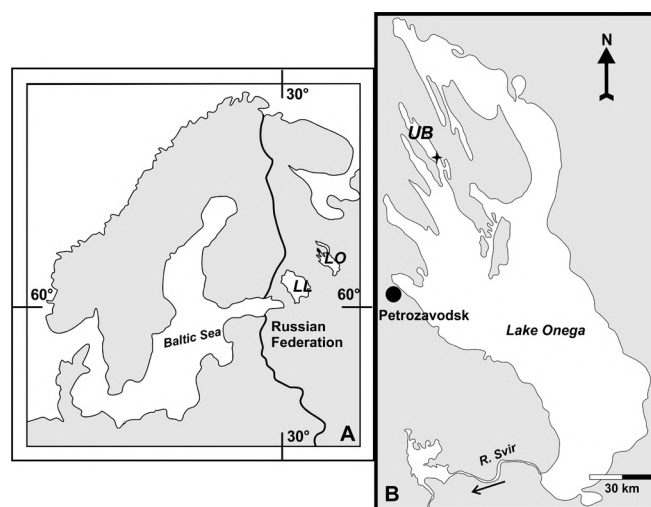


Fig.1. Location map of: A) Lake Onega (= LO; LL = Lake Ladoga), B) the study site (UB = Unitskaya Bay, star indicates the coring site)

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and 3) clayey silt. Samples for the diatom analysis were pretreated following the standard procedure (Jousé et al., 1974). Siliceous cysts of the chrysophytes (golden algae, Chrysophyceae) were counted alongside with diatom valves. Concentrations of both groups of microalgal remains in g^{-1} dry sediment, floristic diversity index (FDI) and “cysts to diatoms” ratio (CY:DI) were subsequently calculated.

3. Results and discussion

Three main stages of the evolution of the Unitskaya Bay were recognized, each characterized with a certain composition of diatom assemblages, FDI and CY:DI values, and abundances of siliceous microalgal remains.

Sporadic finds of planktonic diatoms (*Aulacoseira islandica*, *A. subarctica*, *Cyclotella* spp.) recorded at the earliest stage point to deep-water environments, while extremely low concentrations of diatom valves and chrysophyte cysts (<30000 and $<10000 \text{ g}^{-1}$, respectively) indicate unfavorable conditions for growth and/or accumulation of these algae. Such conditions existed in the Unitskaya Bay during the formation of lateglacial varved clays and early-Holocene homogenous clays. In the Late Glacial, as the Onega Ice Lake occupied the Onega depression the algae growth was limited by nutrients deficiency and low water transparency. Besides, high input of suspended particles delivered by glacier melt waters “diluted” microfossil concentrations in the sediments. In the Early Holocene, the waters of the Unitskaya Bay remained cold and nutrient-poor. High amounts of mineral material were still transported to the lake from the eroded lake shores as the highest rates of the isostatic uplift in PB and BO caused a rapid decrease in the water volume and lake-level lowering (Zobkov et al., 2019). Sporadic finds of reworked Eemian marine diatoms in the diatom record provide an additional evidence for widespread erosional and re-depositional processes. Thus, suspended clay particles in the water column prevented warming-up of the lake waters despite the high summer insolation in the Early Holocene, and lowered the water transparency which limited the growth of algae. While an increase in diatom concentrations was previously recorded already in the homogenous clays pollen-dated to BO (Davydova, 1976), our results suggest that the ecosystem of the Unitskaya Bay remained low-productive during the entire period of the clays formation.

At the next stage, rapidly increasing siliceous microalgae concentrations indicate increased ecosystem productivity apparently resulted from climate amelioration coinciding with the onset of silts accumulation. The predominance of planktonic *Aulacoseira islandica* is characteristic for the lower part of the silts in the Unitskaya Bay as well as in other parts of Lake Onega, in the sediments pollen-dated to AT (Davydova, 1976). Presently, the spring bloom of *A. islandica* in Lake Onega starts already under ice, and continues after the ice-out. Low water temperatures and intense mixing favor its mass development in

the early-spring phytoplankton that continues until the end of the biological spring season when thermal stratification terminates the growth of *Aulacoseira* taxa (Petrova, 1971). As the climate progressively warmed in the Mid Holocene, an earlier onset of its under-ice growth and/or the earlier ice-out could favor *A. islandica*. Additionally, shorter period of the spring circulation and earlier onset of thermal stratification could have limited the growing period for other *Aulacoseira* species that flourish in the late spring (e.g. *A. subarctica*). This made *A. islandica* the only dominant in the spring phytoplankton, and consequently, in the sediment record. The chrysophytes, at present, mainly contribute to the summer phytoplankton in Lake Onega, especially in shallow-water semi-enclosed bays such as the Unitskaya Bay (Petrova, 1971). The highest CY:DI values suggest that chrysophytes outcompeted diatoms during the summer seasons favored by temperature and nutrient conditions of the Mid Holocene.

The following stage is characterized with further increase in siliceous microalgae concentrations (diatoms to $>100 \text{ mln}$, cysts to $>20 \text{ mln g}^{-1}$), higher FDI values, and a predominance of *Aulacoseira subarctica*. This species has not been mentioned in the earlier studies (Davydova, 1976; Petrova 1971) because various morphotypes of *A. subarctica* were previously misidentified as three different taxa, namely *Aulacoseira italica*, *A. italica* ssp. *subarctica* and *A. (distans* var.) *alpigena*. Drastically increased abundances of those taxa were recorded in SB sediments and remained high in SA, which was accompanied by increased diatom species diversity and diatom concentrations (Davydova, 1976). Presently, *A. subarctica* is the most abundant in phytoplankton in the late spring when convective mixing intensifies and the waters warm up, co-dominating *A. islandica*. Mass development of *A. subarctica* in SB and SA could thus indicate a longer duration of the spring circulation period compared to AT that resulted from slower warming of water masses as the climate progressively cooled. High proportions of planktonic *Cyclotella* spp., typical of summer phytoplankton in thermally-stratified lakes are observed at this stage and recorded until present. Decreased CY:DI values might reflect more intense competition for nutrients between chrysophytes and diatoms during the summer seasons. High abundances of *A. subarctica*, *Cyclotella* spp., and siliceous microalgae concentrations are also characteristic for the present-day sediment record of the Unitskaya Bay. Thus the conditions similar to present presumably established here in SB. Continued uplift of the northern part of the Onega basin resulted in a gradual shallowing and weakening of the water exchange between the Unitskaya Bay and the open-water part of the lake, which apart from the climate, also contributed to the local specifics of thermal conditions. Earlier waters warming-up, intense spring turn-over, and earlier onset thermal stratification compared to open-water and deeper areas presently account for earlier seasonal changes in phytoplankton composition of the Unitskaya Bay (Petrova, 1971).

4. Conclusions

The study of the siliceous microalgae revealed three main stages of the evolution of the Unitskaya Bay. In the Late Glacial and Early Holocene, low-productive cold-water environments prevailed. The mid-Holocene climate amelioration resulted in increased ecosystem productivity. Earlier ice-out, shorter spring circulation and earlier onset of thermal stratification compared to present are suggested. The conditions similar to present established in SB, when warming of water masses slowed and duration of the spring mixing increased with the progressive climate cooling.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Geochemical and mineral composition of bottom sediments of the last glaciocedimentation cycle from Lake Onega (NW, Russia)

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ABSTRACT. The study of the geochemical and mineral composition of the bottom sediments of Lake Onega (the Petrozavodsk Bay) described fundamental differences between the chemical composition of sediments formed at the Holocene and Upper Pleistocene. It suggested the reason for mechanical to chemical type of weathering.

Keywords: Lake Onego, bottom sediments, Late Pleistocene, Holocene, geochemistry

1. Introduction

Lake Onega is the second largest and largest body of water in Europe. The lake basin is located between the Archean and Proterozoic rock, and a complex path of tectonic transformations in the continental and marine regime. The last glaciers deepened the depression and covered the relief with moraine, fluvio-glacial, and limnoglacial deposits. Recent Holocene deposits are already formed in lacustrine, nepheloid sedimentation condition.

This work was carried out with the aim of a detailed study of the geochemistry and mineralogy of bottom sediments in Lake Onega.

2. Materials and methods

The object of the study is Lake Onega. The collection of samples was taken by drilling from the ice in March 2019. Cores of bottom sediments of the supraglacial section were taken with entry into the dense layers of glacial sediments of Lake Onega. The work was carried out using a piston system for sampling cores of bottom sediments manufactured by UWITEC (Austria). Bottom sediment cores were sawn along their axis for description and further study of the geochemical and mineral composition.

Elemental analysis of bottom sediment samples was performed by inductively coupled plasma mass

spectrometry on an ELEMENT high-resolution mass spectrometer (FinniganMAT) with a pneumatic concentric Meinhard sprayer. In addition, for this purpose X-ray spectral fluorescence analysis (silicate) was used. The measurements are performed on an X-ray spectrometer "ARL-9900-XP" (Applied Research Laboratories, USA) The study of the morphology, phase and chemical composition of the samples was carried out using a scanning electron microscope "MIRA 3 TESCAN" (Tescan, Czech Republic), equipped with an energy spectrometer "Oxford" (Oxford Instruments, UK) The mineral composition of bottom samples was analyzed by X-ray diffractometry (XRD) using an ARLX'TRA diffractometer (CuK α radiation) (ThermoFisher Scientific (Ecublens) SARL, Switzerland).

Analytical work was carried out at the Analytical Center for multi-elemental and isotope research SB RAS, Novosibirsk, Russia.

3. Results and discussion

At present, the official stratigraphic scheme of the North-West of Russia (Maksimov et al., 2015) includes units that make up the bottom of the lakes (from bottom to top): 1) Tills and fluvio-glacial deposits of the Upper Pleistocene - coarse sand with pebbles, clays with boulders, boulder loams (gIII; fIII, where g - glacial, f - fluvio-glacial); 2) Upper Pleistocene deposits of lakes associated with the Ostashkov stage of the

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Valdai glaciation - banded clays (lgIII, where lg are limno-glacial); 3) Holocene lacustrine deposits - silt and sand (lH, where l - lacustrine)

During the sampling of bottom sediment cores, we uncovered the following deposits from bottom to top: glacial deposits of the Ostashkov stage of the Valdai glaciation (gIIIost), represented by moraines; fluvioglacial deposits of the Ostashkov stage of the Valdai glaciation (fIIIost), represented by medium-fine-grained sands with interlayers of medium-grained sand, which overlaps with the erosive contact of clay; Limnoglacial deposits of the Ostashkovian stage of glaciation (Onega layers) (lgIIIost) in which three members are distinguished.

The lower member is represented by proximal limnoglacial shales (lg1IIIost), representing an irregular interbedding of brown sandy shales and gray shaly sands. Above is a member of rhythmically interbedded gray-brown and brownish-gray banded clays (lg2IIIost). The upper unit of limnoglacial deposits (lg3IIIost) is represented by microlayered clays of gray, light brown, brown-gray color, sometimes with a creamy or greenish tint, which turn into homogeneous light gray fluid-plastic clays. The upper part of the exposed deposits is represented by two packs. Member of homogeneous gray greenish-gray compacted aleuopelitic sediments (lgIII-H) - New Onega layers, lower member; Member of greenish-gray and brownish-gray organogenic-mineral aleuopelitic sediments (silts) (lH) - Novonezhsk layers, upper member.

For the tested horizons, the macro- and microelement composition was studied: glacial-fluvioglacial and limnoglacial deposits have similar spectra (Fig.) of the distribution of macro- and microelements, with a difference in absolute contents (lower concentrations are characteristic of fIIIost-gIIIost). The reason for this is the dominance of quartz in the composition ($\text{SiO}_2 = 91.8$ and 66.5 wt % for fIIIost-gIIIost and lgIIIost, respectively, which is the reason for the lower concentrations of other elements (Table)).

Holocene deposits (lH) differ in elemental composition from glacial-fluvioglacial and limnoglacial

deposits. The main difference lies in the higher content of Fe, Mn, K, P and low content of S (Table). Moreover, the maximum concentration of Fe, Mn and P is observed for the same samples, and the correlation coefficient for Fe-P and Mn-P pairs are 0.94 and 0.97, respectively.

This is also reflected in the mineral composition of bottom sediments: quartz, feldspars, chlorite, illite, Fe and Mn hydroxides, as well as in samples with a high content of phosphorus, the Fe phosphate mineral was found (Strakhovenko et al., 2020). One of the factors regulating the formation of vivianite, as the main antigenic iron phosphate in bottom sediments, is the content of S (Rothe et al., 2016). The Holocene deposits of Lake Onega are characterized by low values of sulfur compare to the Pleistocene deposits. Thus, the content of SO_3 in lH is 0.09 wt %, while in fIIIost-gIIIost and lgIIIost they are 0.14 and 0.26 wt. %, respectively.

The difference in the chemical composition of the Holocene deposits (high contents of Fe, Mn, P) indicates a change in the composition of the incoming material. The reason for this is the change from mechanical weathering during the glacial to chemical weathering today. This also likely explains low content of sulfur. The input of material from shungite rocks that emerge in the north of Lake Onega (mean concentrations $\text{SO}_3 = 0.6$ wt. % (Filippov, 2002)), has decreased due to resistance to chemical weathering.

4. Conclusions

The study of the geochemical and mineral composition of the bottom sediments of Lake Onega in the Petrozovodsk Bay most likely evidenced:

1. Glacial, fluvioglacial, limnoglacial deposits have a similar macro- and microelement composition, differing only in absolute concentrations, which are regulated by the amount of quartz in the composition of bottom sediments.
2. Holocene and Pleistocene deposits was differed as high content of Fe, Mn, K, P and low S.
3. The Holocene bottom sediments is characterized by the chemical composition due to to change of mechanical to chemical weathering.

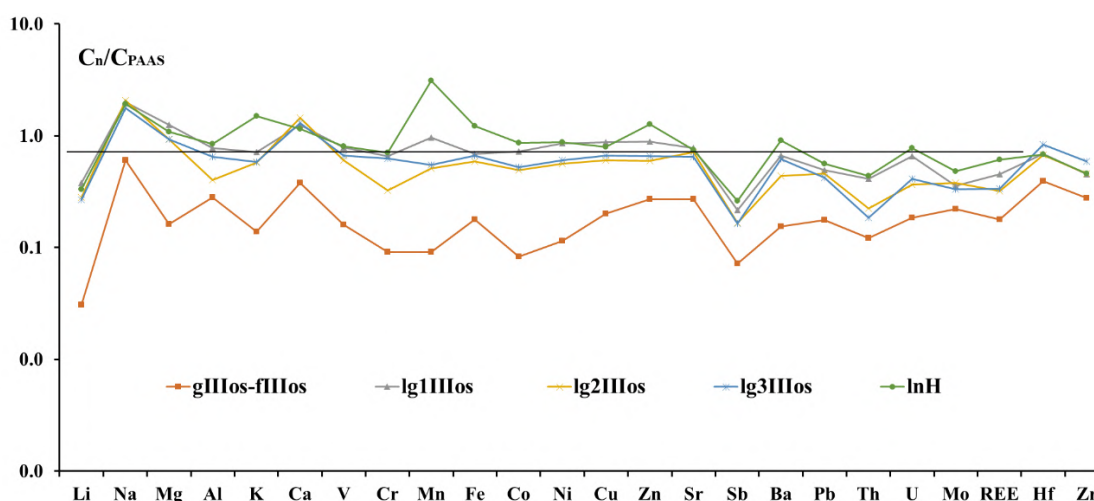


Fig. Distribution of element contents in bottom sediments normalized to PAAS (Post-Archaean Australian Shale) (Taylor and McLennan, 1985).

Table. Chemical composition of bottom sediments of Lake Onega, content in wt. %

	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃
gIIIos- fIIIos	91.83	0.18	3.04	1.32	0.02	0.38	0.62	0.61	0.57	0.04	0.14
lg ₁ IIIos	59.93	0.76	15.88	7.15	0.15	3.25	2.25	2.58	3.20	0.15	0.34
lg ₂ IIIos	70.19	0.58	12.18	4.51	0.07	2.14	2.22	2.41	2.31	0.12	0.21
lg ₃ IIIos	69.43	0.64	12.07	4.94	0.08	2.08	2.14	2.16	2.30	0.12	0.31
lnH	58.17	0.70	13.94	8.96	0.43	2.51	1.97	2.26	2.53	0.34	0.09

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Conflict of interest

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Quantitative assessment of carbon sequestration by sapropel deposits inferred from Lakes Peschanoe and Nizhnee (Western Siberia, Russia)

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ABSTRACT. Comprehensive studies of chemical and mineral composition of two lake systems on the territory of the Baraba lowland in the south of western Siberia was carried out. The reserves of sapropel and carbon were calculated for each lake. Sources supply of material and forms of carbon burial in the bottom sediments were identified.

Keywords: sapropel, small lakes, Baraba lowland, Novosibirsk region, carbon, carbon sequestration

1. Introduction

One of the most significant consequences of human impact on the natural environment is planetary changes in the optical properties of the atmosphere in the infrared region of the spectrum as a result of anthropogenic emission of greenhouse gases and their subsequent accumulation. This process leads to a change in the radiation balance of the Earth and global climate change (Izrael et al., 2002). Emissions from fossil fuels began before the industrial era, but they are the dominant source of anthropogenic emissions to the atmosphere (since 1920) at the moment (Le Quéré et al., 2013). The main component of emissions from fossil fuels is carbon dioxide (CO₂). It is the leading biogenic chemical agent involved in the carbon cycle (C), as well as one of the most important greenhouse gases (Climate change, 2014). Stabilizing elements of the Earth's climate system providing runoff and accumulation carbon is vegetation, mainly forest ecosystems of the planet (Pan et al., 2011; Le Quéré et al., 2013). For the territory of Russia, forest ecosystems are also objects of carbon accumulation (Shvidenko and Schepashchenko, 2014). However, for the territory of Western Siberia, especially for the southern and middle parts, lake and swamp ecosystems are carbon depositing ecosystems (Isaev et al., 1995).

A review study (Tranvik et al., 2009) showed that global storage of organic carbon in inland water sediments exceeds organic carbon sequestration at the ocean floor, making it necessary to account for carbon stocks in inland water sediments for regions with high swampiness and lakeness.

The objects of study in this work are two lakes (Peschanoe and Nizhnee) located in the forest-steppe landscape zone on the territory of the Baraba lowland in the south of Western Siberia. The studied lakes are located in 10 km from each other.

Both lake basins were formed in a suffusion-subsidence pattern in an interridge depression (Strakhovenko et al., 2019). In terms of area, the lakes are small ($S_{\text{Peschanoe}} = 126$ ha, $S_{\text{Nizhnee}} = 64$ ha), by geographical location they are intrazonal, according to thermal classification they belong to lakes with changing temperature stratification, they are drainless, shallow (the depth of Lake Peschanoe - 1.67 m, Lake Nizhnee - 1.25 m), freshwater and mesotrophic-eutrophic reservoirs. The waters of the lakes are bicarbonate-sodium in composition.

2. Material and methods

Fieldwork was carried out in the summer. In each lake, the morphometric and hydrological characteristics water, soils of catchment areas, bottom sediments (BS), and prevailing vegetation were studied. Sampling of BS was carried out with a cylindrical sampler with a vacuum lock designed by NPO Typhoon (diameter 82 mm, length 100 cm) from a catamaran at pre-marked sampling points (sampling network density 1 point per 12 ha). The design of the sampler allows sampling without disturbing the stratification of sediments. The core analysis of bottom sediments was carried out on site. The structure of the sapropel deposit was studied using an echo sounder and direct sounding (the density of the sounding network is 1 point per 1.6 ha). The

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total volume of sapropel is defined as the product of the average thickness of sapropel and the area of the lake. Sapropel reserves are defined as the product of the volume of sapropel and the yield of sapropel at 60% moisture.

Water sampling is carried out according to standard methods (GOST 31861-2012, 2014). In the fieldwork, the pH, Eh and mineralization were determined using the ANION-7000 device. Soil sampling was carried out with a metal ring (diameter 82 mm and height 50 mm). The binding of sampling and sounding points was carried out using a GARMIN GPSMAP 86S GPS navigator. Sample preparation consisted in drying to an air-dry state, followed by grinding.

The multi-element spectra of the averaged values of the studied elements normalized to the values of the concentrations of the Upper Continental Crust by (Wedepohl, 1995) with further comparison with the data of morphology and phase composition and mineral composition of BS.

Analytical studies were carried out at the Analytical Center for multi-elemental and isotope research SB RAS, Novosibirsk: AA, ICP-MS, X-ray diffraction analysis, gamma spectrometry, SEM studies, isotope studies and the elemental composition of the organic part of sapropel.

3. Results and discussion

To determine the sources of material for sapropels from Lakes Peschanoe and Nizhny, we compared the chemical composition of the substrate, soils, and sapropel. The chemical composition of the sapropel of Lake Nizhnee almost completely corresponds to the substrate and soils, but has lower values due to impoverishment by organic matter. Grains of quartz, feldspars, micas, and chlorite represent the mineral composition. Biochemogenic formation is represented by fromboidal segregations of pyrite indicating about reducing conditions. The composition of deposits along the section was slightly varied. In general, the deposit is homogeneous and belongs to the organic-mineral type and the siliceous class of sapropel. According to Ermolaeva et al. (2022), sapropel in Lake Nizhnee has a macrophyte-planktonic genesis. The rate of autochthonous organic matter is 34%, and more than half of the sediment flow comes from the watershed. The rate of accumulation of sapropels is on average 1.25 cm per year. The calculated reserves of sapropel are 700 thousand tons at water content in 60%. With an average ash content in 38.7% and 33.97% carbon content in the organic part. Thus, about 58 thousand tons of organic carbon were buried in the sapropel deposit. The calculation of dissolved carbon in water was also carried out - 0.05 thousand tons.

Unlike Lake Nizhnee, two classes of sapropel are identified in Lake Peschanoe – calcium and siliceous. In the lake, the formation of a sapropel deposit proceeded not only by detecting the inflow of terrigenous material, also an authigenic mineral formation of low-magnesian calcite played a significant role. The

authigenic formation is associated with biochemogenic processes at the bottom of the lake, where the decomposition of organic matter will release abundant CO₂ in concentrations sufficient for the formation of carbonates (Ovdina et al., 2020). The silicon class of sapropel is widespread in the northern part of the lake and occupies the middle part of the deposit, wedging out closer to the center of the lake. The terrigenous part throughout the lake is the same and is represented by quartz, feldspars, mica, and chlorite. Biochemogenic authigenic formation is represented by low-magnesian calcite, aragonite and fromboidal pyrite. The biogenic component is represented by frustules of diatoms consisting of silica, as well as fragments of calcite shells. The calculated reserves are equal to 1412 thousand tons and 252 thousand tons of calcium and silicon classes of sapropel, respectively. Organic carbon reserves are estimated at 97 thousand tons and 7 thousand tons for each class. Since our study showed that the main forms of calcium in BS are calcite and aragonite, it became possible to estimate the reserves of carbon buried in the form of mineral matter. The calculated reserves are equal to 29.4 thousand tons, which is almost a third of all buried carbon in the lake. Dissolved carbon in water is estimated at 0.39 thousand tons.

4. Conclusions

The total carbon reserves for each lake are 58.005 and 133.79 thousand tons. The main source of carbon in BS is vegetation, which in turn captures carbon from the atmosphere in the process of photosynthesis. At the same time, there are lakes in which the decomposition of organic matter in the bottom of the lake creates favorable conditions for the biochemical authigenic formation of carbonates. As result, a significant amount of carbon can be accumulated.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.

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Geochemical indication of the Holocene climatic changes in sediments of Bolshoi Bagan Lake, Southern West Siberia

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ABSTRACT. Our study of the Holocene sediments of shallow saline Lake Bolshoy Bagan located revealed the following stages of the lake evolution: (I) Appearance and maturing of the lake 9.1–5.8 ka BP; (II) rise in water level 5.8–2.3 ka BP; and (III) shallowed lake 2.3–0 ka BP.

Keywords: bottom sediments, geochemistry, saline lake, Holocene, paleoclimate

1. Introduction

Despite a noticeable increase in paleoclimatic research in recent years, there is still an acute shortage of reliable data on the climate of the past, including for the inland regions of the largest Asian continent. (Sklyarov et al., 2010; Solotchina et al., 2019). Thus, with a large number of paleoclimatic studies for the steppe biome of the European part of Russia, the vast territory of the south of Western Siberia is a “blank spot” in our understanding of the evolution of lake systems and climate dynamics in the Holocene. Studies of the sediments of small lakes in the south of Western Siberia for the purpose of carrying out paleoclimatic reconstructions are not numerous and are based mainly on data from palynological and diatom analyzes and the distribution of macro- and microelements (Blyakharchuk, 2003; Andreev et al., 2004; Zhdanova et al., 2019). The most informative are the bottom sediments of small salt lakes, which, due to their small size, are exceptionally sensitive to climate change (Last, 2002). Unlike large water bodies, they are less conservative under external influences, since their small size causes their instability depending on climate change (Sklyarov et al., 2010). Therefore, it is small lakes that can provide high-resolution climate records.

2. Materials and methods

Mineral Lake Bolshoi Bagan is located in the south-west part of the Baraba forest-steppe, Novosibirsk Region, near the Kazakhstan boundary. The our days

(2019) lake has linear size 4×2 km, area 5.6 km², and depth 0.65 m. A sign of the modern drying of the lake is the salt plain in its southern part, the former bay. On the slopes of the basin of the lake there are dozens of coastlines, indicating that the lake was 10 meters higher than it is now. The lines continue on the slopes of the neighboring basins, which means that there was a much larger lake at the maximum level ascent. We drilled a well in the central part of the lake (N 53.89804°, E 77.12836°) by a Livingston-type piston probe to a depth of 3.75 m. The lake sediments are 2.84 m thick coarsely laminated silts, and the underlying sediments derive from Quaternary sands typical for the area.

The age of the lake sediments is determined by 15 radiocarbon dates (Fig. 1). We investigated the mineralogy and geochemistry of the lake sediments and the composition of their pore waters. The concentrations of anions in the pore water were determined by titrimetry (HCO₃⁻) and capillary zone electrophoresis. The total dissolved organic carbon (DOC) in pore water was determined on an *Analytik Jena AG Multi N/C 2100S* analyzer. The contents of chemical elements in bottom sediments and pore water were determined by ICP-AES. The mineral composition of the sediments was studied by XRD, using a *DRON-4* diffractometer with CuKα radiation. The total organic carbon (TOC) in bottom sediments was evaluated by Tyurin's method. The grain size of the sediment was measured on Analysette 22 MicroTec.

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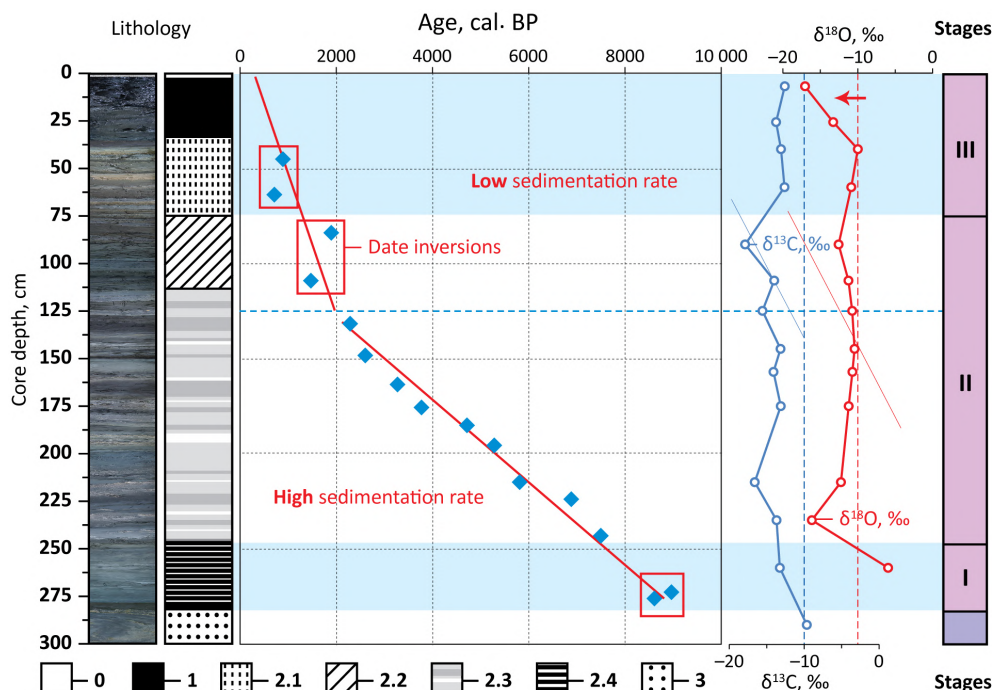


Fig.1. Radiocarbon age of the Bagan Lake sediments and lithology of the core. 0. salt; 1. black watered silt; 2.1. grayish and greenish laminated watered silts, 2.2. denser dark-gray silts, 2.3. denser laminated grayish and brownish silts, 2.4. light-grayish and bluish silts; 3. underlying sands.

3. Results and discussion

The underlying substrate is geochemically different from the lake sediments (Fig. 2). It showed the highest portion of terrigenous minerals: quartz and plagioclase. The presence of halite indicates salinization of the substrate. Its chemical composition indicates high Si and lowered Ca and Mg in comparison with the lake sediments. We recognize two layers of the substrata; the upper (310–280 cm) is indicative by sharp decrease in Al, increase in Sr and in Na and Ti/Al ratios. We suggest soil origin of this blackish color layer and low part of clay in it.

For lake sediments we envisage the following stages of development.

Stage I (~9.1–5.8 cal ka BP). The initial stage shows lowered terrigenous component of the sediment due to increase in calcite, chlorite and mica. The radiocarbon-based age model indicates the lowest sedimentation rate, while the arithmetic mean particle diameter (AMD) 50.6 μm in this interval is the largest for the whole lake part of the core. Therefore we suggest that the lake had rather high water level during this stage. The stage shows increase of Al, Fe, and Ni, which suggests an increase in the flow of aluminosilicate minerals into the lake. The increase in TOC indicates an increase in bioproductivity. We suggest low salinity of the lake water, which contributed to the active deposition of gypsum against the lowest halite content. However, the lake was gradually salinized. This is illustrated by increase of the proportion of Mg-carbonates and by changes in ionic composition of the sediment pore waters.

Stage II (5.8–2.3 cal ka BP). Transportation of terrigenous minerals was low in the first half of the stage and considerably increased in the second. By authigenic

minerals, it was a gypsum stage with sharp increase in proportion of halite in the second half. The succession of precipitation of minerals infers the bottom-to-top increase of alkalinity and salinity of the lake. The concentrations of Na^+ , Cl^- , SO_4^{2-} increase, and Ca^{2+} decrease in the pore waters, which confirms the trend to salinization. The low Ca and Mg carbonate content in the interval of 230–160 cm can be an indicator of a higher level of water in the lake. This is indicated by the drop of halite and terrigenous minerals—mica, quartz, and chlorite. In the subsequent part of Stage II, interval 160–110 cm, the lake geochemistry abruptly changed: gypsum sharply decreased and halite and calcite became the dominated authigenic minerals. At the same time, the portions of mica, quartz, and chlorite also increased. The higher Ca and Mg and decreased Al, Fe, and Si, also confirm a sharp change of the lake geochemistry: salinization and high terrestrial input.

Stage III (2.3–0 cal ka BP). The maximal contents of halite and calcite suggest the highest salinity of the lake. The grain size of the sediments is the lowest (AMD=17.5 μm) and the portion of clay minerals (chlorite) and mica increases. General Ca decreases as well. This means a significant lowering and salinization of the lake with the maxima 0.7–0.4 cal ka BP reflected in an increased portion of halite and decreased calcite. Maximum of carbonates is characteristic for the recent time of the lake development. The presence of aragonite, dolomite and high-Mg calcite reflects a negative water balance, which leads to further salinization of the lake.

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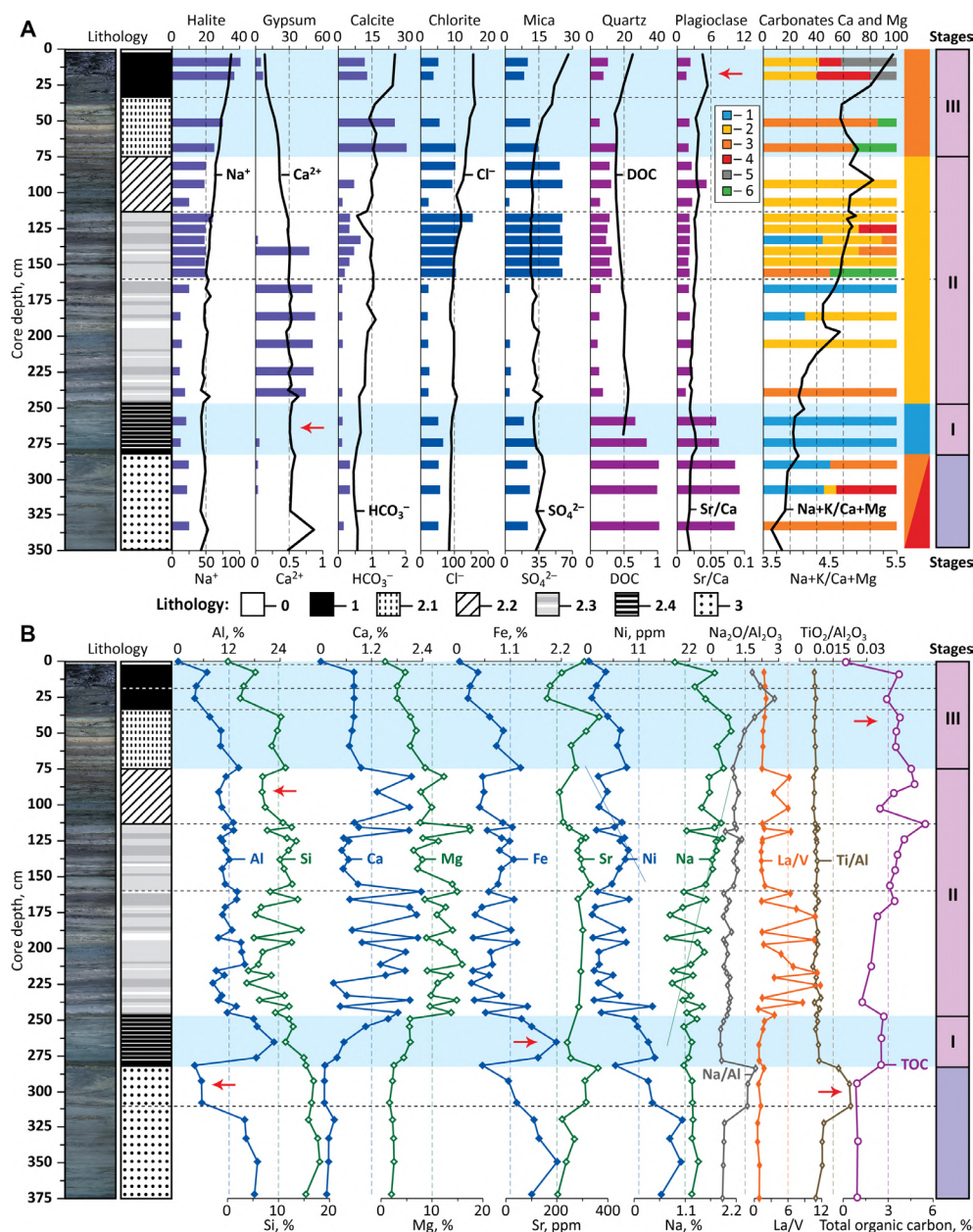


Fig.2. Mineralogical and geochemical data. (a) Mineral composition and carbonate mineralogy: 1. calcite, 2. low-Mg-calcite (about 5% Mg), 3. medium-Mg-calcite (10–12% Mg), 4. high-Mg-calcite (40–45% Mg), 5. aragonite, 6. dolomite. (b) Distribution of chemical elements and geochemical indicators of sedimentation (La/V, sodium module $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ and titanium module $\text{TiO}_2/\text{Al}_2\text{O}_3$).

performed at the Analytical Center for Multi-element and Isotope Studies of IGM SB RAS.

Conflict of interest

The authors declare no conflict of interest.

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Geochemical indicators of climate changes in Southwestern Siberia (Russia) in the Holocene sediments of Lake Itkul

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ABSTRACT. We present the results of study the Holocene sediments of Itkul Lake, a shal low brackish lake with carbonate sedimentation, located in the eastern part of Baraba lowland (Southwestern Siberia, Novosibirsk Region). A 1.8 m thick core of the Holocene (7.9 ¹⁴C yr) sediments of Itkul Lake has been studied. Based on the geochemical and lithostratigraphic properties of the bottom sediments, we have established the following stages of the lake evolution: (I) the beginning of sedimentation, 7.8–7.0 ¹⁴C ka; (II) extreme shallowing with a probable complete drying, ~7.0–5.5 ¹⁴C ka; (III) rise in the water level, ~5.5–4.3 ¹⁴C ka; (IV) repeated shallowing, 4.3–2.8 ¹⁴C ka; and (V) subsequent watering, 2.8–0 ¹⁴C ka. At present, the lake again tends to shallowing.

Keywords: bottom sediments, geochemistry, XRD analysis, Holocene, paleoclimate

1. Introduction

One of the key sources of information about the climate changes in intracontinental regions is represented by the sections of bottom sediments from lakes characterized by different mineralization and trophicity. Lake basins are ubiquitous and abundant in the Siberian region, and their areas, salinity, and predominant sedimentation types vary in a wide range. However, it should be noted that different parts of the Siberian region are not equally studied in terms of both particular lakes and lake systems (Solotchina et al., 2021). Therefore, the respective research problem is to unravel in sediments the indicators of natural environments (in particular, temperature and degree of drying/wetting of the environment) in order to construct regional paleoclimatic records. The present work was aimed at obtaining the Holocene climate record from detailed mineralogical and crystallochemical studies of bottom sediments of Itkul Lake, one of the minor lakes in the southern West Siberian Plain.

2. Materials and methods

Lake Itkul lies 2.5 km from the Chulym, beyond its valley, and is separated from it by a linear hill (low ridge). Lake Itkul is located at the eastern edge of the area of an aeolian low ridge, in a lowland with Chany Lake at the center. The low-ridge strata are a bed of Late

Glacial loess-like loams overlying all relief elements, except for river floodplains. These deposits are exposed along the Itkul Lake shores and are the main supplier of lacustrine sediments. Hollow Itkul Lake lies in the depression between low ridges and has a shallow bay in the west. The lake without a bay is 5.2 km in length (with a bay, 8.7 km), the maximum width is 3.7 km, the average depths in its central part are ~1.5–1.8 m (the maximum depth is 3 m), the water area is 15.1 km², and the drainage area is 124 km². Itkul Lake is a lake with a small watershed (the drainage factor is 8.2). The lake is fed with spring water and precipitation and is characterized by border overgrowing.

Two boreholes were drilled by the vibration method to depths of 1.8 and 1.9 m in the central part of the lake (55°03'54"N, 81°02'47"E), using a Livingstone piston sampler. The penetrated lacustrine sediments are ~1.6 m thick and are underlain by low-ridge rocks. The contents of Al, Ca, Mg, Sr, Na, K, Fe, and Mn, in bottom sediments were measured by ICP-AES. The mineral composition of the sediments was studied by XRD, using a DRON-4 diffractometer with CuK α radiation. The quantitative content of carbonates in the sediments was determined following the technique described by Vorobieva (1998). The content of total organic carbon (TOC) in the samples was evaluated by Tyurin's technique (Vorobieva, 1998). We estimated the contribution of terrigenous calcium (Ca_{ter}, %) to the sediments, taking Al as a reference element (the

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contents of Al and Ca in the upper continental crust are 7.74% and 2.94%) as follows (Maltsev et al., 2020):

$$Ca_{ter} = (Al_{smp} / Al_{cr}) \cdot Ca_{cr}$$

where Al_{smp} is the content of Al in the certain lacustrine sediment horizon, Al_{cr} is the content of Al in the upper continental crust, and Ca_{cr} is the content of Ca in the upper continental crust.

3. Results and discussion

Lake Itkul formed in the Middle Holocene at 7.8 ^{14}C ka (8.8 cal ka), under the influence of a rapid and drastic change of the cold arid climate by the warm humid one (Fig. 1). After the melting of a glacier, a lake began to form at the place of loess-like loams.

Stage I. At the initial stages of the lake formation (Fig. 1), at ~ 7.8 – 7.0 ^{14}C ka, silicate material (quartz, K-feldspar, mica, chlorite, and kaolinite) actively accumulated in the depth range 162–145 cm of the bottom sediments. This interval has the highest contents (%) of Al (5.6), Na (1.3) and K (2.0) supplied into the lake mostly with terrigenous products of destruction of Quaternary blanket deposits (Fig. 2). All this indicates the high standing of the lake and an active terrigenous supply from the drainage areas into the lake. At the high water level and low salinity of the lake, carbonates (calcites with a minimum impurity of Mg) poorly precipitated. A low intensity of carbonate sedimentation reflects the warm and humid climate dominated. It is at the stage of the Itkul Lake formation (depth range 162–145 cm), during the high level and low salinity, that the water lacked Mg-calcites and had low total contents of carbonates.

Stage II. At the stage of the lake shallowing (depth range 145–130 cm), ~ 7.0 ^{14}C ka, with a significant development of biota (mollusks), the contents of Mg-calcites and aragonites reached their maxima on the

background of an increase in TOC content to 7.1% (Fig. 1, Fig. 2). The depth range 136–138 cm corresponds to the maximum shallowing of the lake throughout its evolution. This is confirmed by the highest contents of carbonates and by domination of aragonite over calcites and of Mg-calcite over $CaCO_3$ in this interval. Traces of gypsum indicated a strong shallowing of the lake and an increase in salinity. The maximum contents of Sr in the range 136–138 cm also reflect a strong shallowing of the lake. The Sr/Ca ratio (indicator of water salinity) increases in the range 138–136 cm, which indicates the maximum salinity of the lake water in the corresponding period. The contents of Mg in this range decrease less than the contents of Al, K, Na, and Fe, whereas the content of Ca drastically increases, which testifies to the active precipitation of Mg-calcites at the shallow-water stage of the lake evolution, when the produced chemogenic carbonates, mainly Mg- $CaCO_3$, contained most of the total Mg. The most active precipitation of carbonates in this range is evidenced by the maximum increase in the total contents of Ca.

The upper part (depth range 130–0 cm), we observe a tendency for a slow stepwise rise in the lake level and the lake freshening. This process was accompanied by periodical slight fluctuations from shallowing to watering of the lake.

Stage III. After the shallowing of the lake at ~ 7 ^{14}C ka, there was a rapid rise in its water level at 7.0–5.5 ^{14}C ka (depth range 130–125 cm) (Fig. 1). This range is characterized by a decrease in the contents of carbonates. A drastic drop in the contents of Ca and Sr in the range 130–120 cm on the background of an increase in the contents of Al and Fe indicates a rise in the lake water level. This rise is confirmed by higher contents of “Al group” elements, reflecting a more intense terrigenous input. The increase in the content of Ca_{ter} to 2.0% at a depth of 130 cm also confirms a rise in the lake water level (Fig. 2).

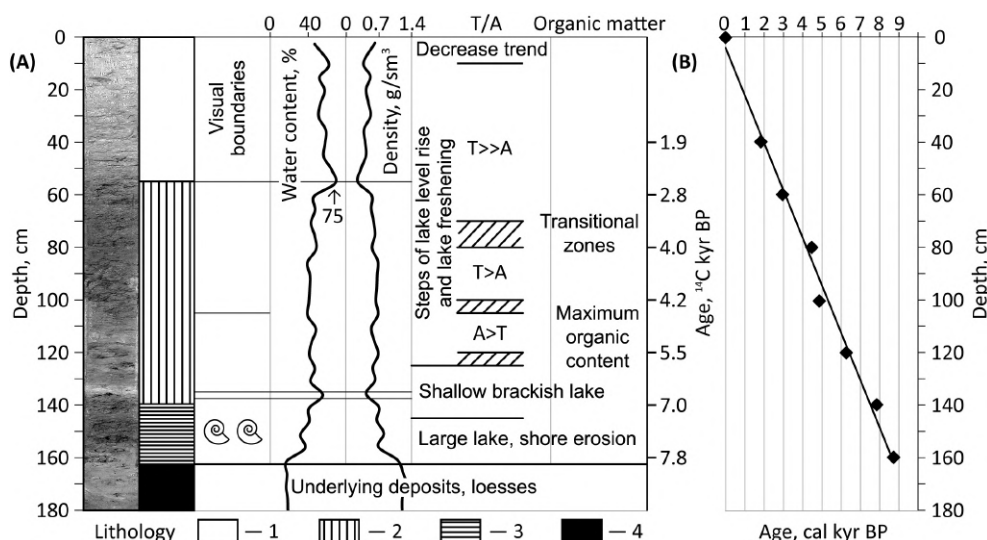


Fig.1. Structure of bottom sediments, changes in the depositional environment (A) and age model (B) of Itkul Lake. T — terrigenous fraction of the sediments; A — authigenic fraction of the sediments. Lithology: 1. 0–55 cm, light gray loam; 2. 55–138 cm, more compact dark gray loam, including darker clay with a sandy material (range 55–100 cm); 3. 138–162 cm, dark brown argillaceous material with fragments of mollusk shells; 4. 162–180 cm, underlying dark gray loess-like loams. The ^{14}C age of the sediments was determined by accelerator mass spectrometry.

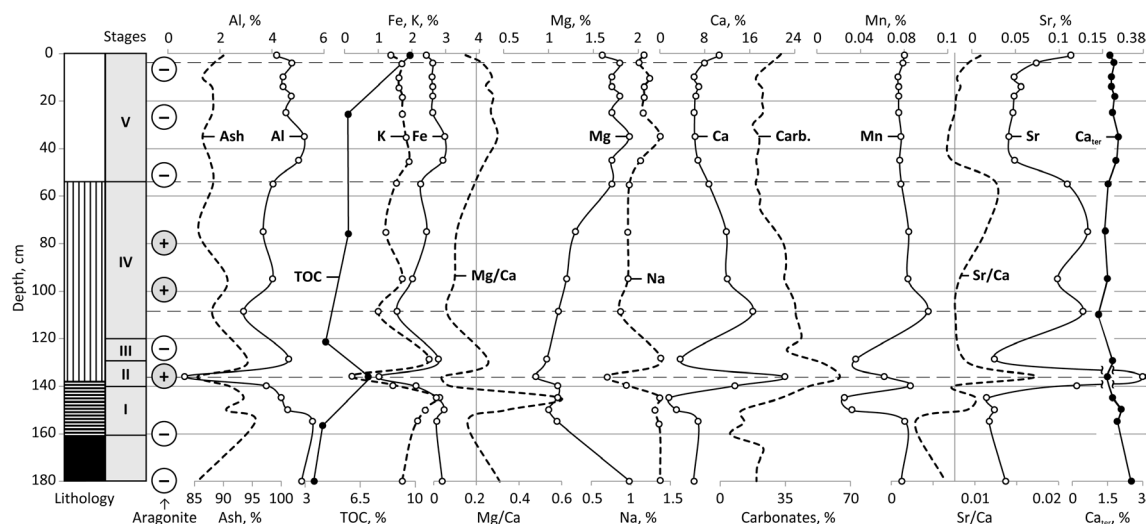


Fig.2. Distribution of ash content, carbonates (Carb.), total organic carbon (TOC), and chemical elements throughout the bottom sediment column. “+”, the presence of aragonite in the sediments (XRD data), “-”, the absence of aragonite.

Stage IV. At ~ 5.5 – 2.8 ^{14}C ka, the lake water level fell (depth range 125–55 cm) as a result of the water evaporation and a less intense water inflow, which led to a higher lake salinity (Fig. 1). Thus, the conditions became favorable for the precipitation of carbonates; this was reflected in the increased contents of Ca in the sediments. Note that the depth range 120–100 cm (5.5 – 4.3 ^{14}C ka) is characterized by the maximum shallowing of the lake over the period 5.5 – 2.8 ^{14}C ka. The increase in the contents of Ca and Sr and the decrease in the contents of Mg and Al in the depth range 120–55 cm might indicate changes in the lake water parameters (salinity, carbonate alkalinity, pH, and temperature) and, hence, a more active chemogenic precipitation of calcium carbonates from the Mg-poor water. Chemogenic carbonates became enriched in Sr, which is confirmed by the significant Sr enrichment of this horizon as compared with the underlying ones. The Sr/Ca ratio increases in the middle depth range (100–55 cm) of the sedimentary strata which indicates the increases salinity of the lake water in this period (Fig. 2). The amount of Mg-calcites in it is smaller than that at the previous shallowing stage (depth range 140–130 cm). This indicates a smaller shallowing of the lake than that marked in the depth range 145–130 cm. The range 120–100 cm is characterized by the maximum (for this stage) drop in water level and an increase in water salinity: domination of Mg-CaCO_3 over CaCO_3 , a drastic increase in the content of carbonates, and the absence of aragonite. The contents of Al and Fe significantly decrease on the background of the stable contents of Mg and a drastic increase in the contents of Ca and TOC.

Our colleagues (Solotchina et al., 2019) combine stages III and IV into one big stage III, which covers the core interval of 120–65 cm. Stage III was quite long, from about 5.5 to ~ 3.0 ^{14}C ka. Sediments formed during the Subboreal period the climate of which was colder and drier compared to the Atlantic one. This stage is characterized by a higher water level in the lake accompanied by its freshening (Solotchina et al., 2019).

Stage V. An increase in the lake water level and a decrease in water salinity (depth range 55–0 cm, 2.8 – 0 ^{14}C ka) strongly restrained carbonate formation (and, hence, led to a decrease in the content of Ca in the sediments) on the background of an intense inflow of terrigenous components (Al, K, Na, Fe) (Fig. 1, Fig. 2). At this stage of the lake watering, the contents of Ca and carbonates in the sediments decreased, which was expressed as a significant decrease in the portion of Mg-CaCO_3 and the absence of aragonite. A terrigenous input increased, as evidenced by much higher contents of Al, Fe, Mg, and Na (Fig. 2) and a higher content of Ca_{ter} as compared with the underlying sediment intervals.

The composition of sediments formed at the current stage of the lake evolution (10–0 cm, the last ~ 100 yr) shows an increase in water salinity and in the contents of Ca and Sr in the sediments and a slight increase in the amount of Mg-CaCO_3 . There is a positive Sr/Ca trend in the uppermost sediment intervals (10–0 cm), which points to a current increase in water salinity. Hence, the lake tends for the next shallowing. Solotchina et al. (2019) identify this interval as a separate stage in the evolution of the Itkul Lake.

4. Conclusions

Based on the geochemical and lithostratigraphic properties of the bottom sediments, we have established the following stages of the Lake Itkul evolution: (I) the beginning of sedimentation, 7.8 – 7.0 ^{14}C ka; (II) extreme shallowing with a probable complete drying, ~ 7.0 – 5.5 ^{14}C ka; (III) rise in the water level, ~ 5.5 – 4.3 ^{14}C ka; (IV) repeated shallowing, 4.3 – 2.8 ^{14}C ka; and (V) subsequent watering, 2.8 – 0 ^{14}C ka. At present, the lake again tends to shallowing.

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Conflict of interest

The authors declare no conflict of interest.

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Application of European diatom indices for paleolimnological reconstructions of Lake Tavatui (Middle Urals, Russia) ecosystem changes

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ABSTRACT. Diatom European indices are applied for assessment of water quality and eutrophication. The research is focused on application of diatom European indices for paleolimnological reconstructions of Lake Tavatui (Middle Urals, Russia) ecosystem changes. Among 23 calculated indices, only IBD, IPS, and IDG were compliant with the condition for the availability of ecological information for at least 60% of the assemblage species and the 60% abundance of these species for all samples of sediments core. There was no correlation between indices due to the different system of counting and pollution sensitivity of species in the same genera in the indices system. Only IPS have negative correlation with diatom inferred total phosphorus. The results based on IBD was not reliable due to its correlation with certain species and its substantial impact into index value. Inapplicability of IDG was due to the fact that this index is based on the ecology of genus which often contains species with different ecology.

Keywords: diatom indices, diatoms, lake sediments, eutrophication, palaeolimnology

1. Introduction

European diatom indices are widely used in assessment of water quality and eutrophication. To determine the drivers of lake eutrophication, it is necessary to study the dynamic of lake ecosystems using palaeolimnological reconstructions. A study conducted on 72 lakes of the Southern and Middle Urals showed that 14 of the 23 European diatom indices correlated with nutrient variables, despite the difference in sampling methods and the type of aquatic ecosystem for which the diatom index was developed (Maslennikova et al., 2022). The purpose of this research is to test European diatom indices for paleolimnological reconstructions of Lake Tavatui ecosystem changes.

2. Materials and methods

In this study, we calculated diatom indices for the Lake Tavatui (Middle Urals) sediments core. The results of the diatom analysis and diatom-inferred water parameters reconstructions of Lake Tavatui were described in details in previous article (Maslennikova, 2022). European diatom indices were calculated using Omnidia 6.1.4. software (Lecointe et al., 1993). The main reason of diatom indices inapplicability was insufficient representation of diatom species of

the Ural lakes in the indices datasets (Maslennikova et al., 2022). So, the interpretation was carried out if the ecological information in index dataset was available for at least 60% of the assemblage species, and the abundance of these species was at least 60% of the assemblage abundance. Pearson correlation was applied to determine the relations between the indices and diatom inferred total phosphorus (DI-TP) and electrical conductivity (DI-EC) of lake water.

3. Results

Only IBD (Biological Diatom Index) (Lenoir and Coste, 1996), IPS (Specific Pollution Sensitivity Index) and IDG (Generic Diatom Index) (Cemagref, 1982) were compliant with the “condition of 60%”. There was no significant positive correlation between these indices (Fig.). IPS and IBD negatively correlated with TP ($r = -0.7$ for IPS and $r = -0.3$ for IBD). For lower (11.7-7.9 cal ka BP) and upper (from 7.9 cal ka BP to 2009 AD) part of the core correlations increased ($r = -0.8$ for IPS and $r = -0.4-0.5$ for IBD). In addition, IBD correlated with EC ($r = 0.8$). However, when analyzing the upper and lower parts of the core, the correlation disappeared. IDG related to EC ($r = -0.7$) and TP ($r = 0.43$) for the whole core, to EC ($r = -0.5$) for the upper part and to TP ($r = 0.7$) for lower part of the core.

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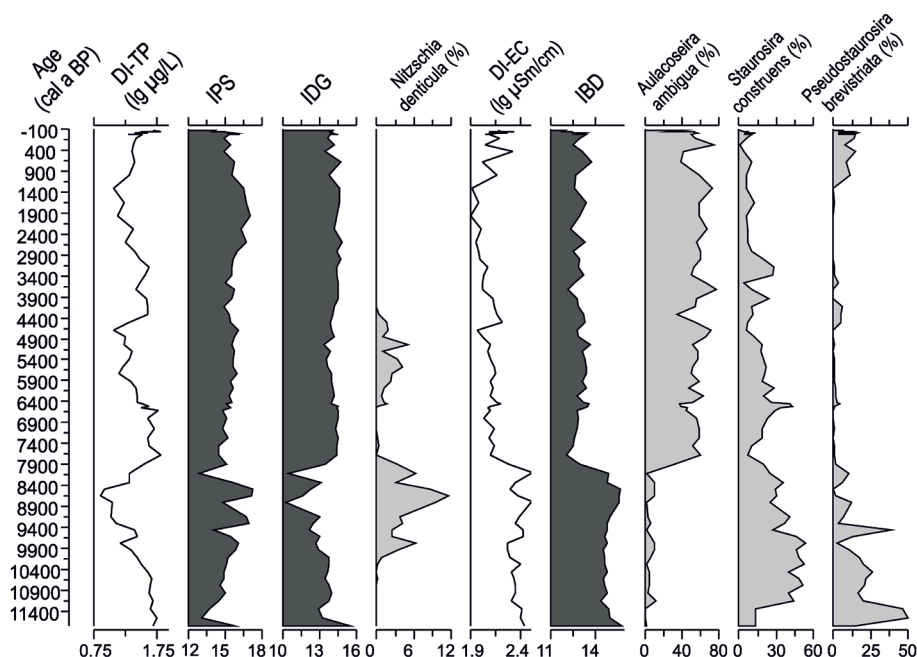


Fig. Lake Tavatui sedimentary record of changes in diatom indices, DI-TP, DI-EC and diatom species.

4. Discussion

Theoretically, the indices should positively correlated with each other and had a negative relationship with DI-TP and optionally with DI-EC. The lack of correlation between indices and false positive correlations with DI-TP and DI-EC could be associated with a different way of indices calculating, as well as differences in indicative value and pollution sensitivity of the same species for the indices. The main diatom assemblage shift at 7.9-8.1 cal ka BP was expressed as shift from *Staurosira construens* Ehrenberg and *Pseudostaurosira brevistriata* (Grunow) D.M. Williams & Round to *Aulacoseira ambigua* (Grunow) Simonsen and *Aulacoseira granulata* (Ehrenberg) Simonsen assemblage. According to IBD system, *Aulacoseira ambigua* and *A. granulata* are more likely to occur in waters of a lower class than *Staurosira construens* and *Pseudostaurosira brevistriata* (Coste et al., 2009). Therefore, with an increase in the number of *Aulacoseira ambigua*, the IBD index sharply decreased, which caused a correlation with EC. Indicative value and pollution sensitivity for above mentioned species in IPS and IDG system are almost the same (Cemagref, 1982). The differences in these indices are due to the fact that IDG is based on the ecology of genus. The main differences between IPS and IDG were observed in periods of *Nitzschia denticula* Grunow increase (Fig.). This species characterized by high pollution sensitivity in IPS system. At the same time, the genus *Nitzschia* have low pollution sensitivity in IDG system. So, then IPS increase, IDG decrease.

5. Conclusions

Thus, assessment of European diatom indices for palaeolimnological reconstructions of Lake Tavatui showed reliable results only for IPS, which had a strong

correlation with DI-TP. Indices mismatch was explained by the different system of diatom indices counting, as well as the different pollution sensitivity of species in the same genera.

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Conflict of interest

The authors declare that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The Anthropocene evolution of the Aral Sea ice gouging derived from the bottom topography

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ABSTRACT. Ice gouging landforms on the exposed bottom of the Aral Sea give a possibility to get a profound knowledge about processes of the ice-bottom interaction during the level fall. We analyzed ice scours in the different parts of the Aral Sea using geomorphological and remote methods and evaluated the paleoreconstruction of ice gouging processes in the Anthropocene.

Keywords: level change, ice scours, ice ridges, geomorphological methods, remote sensing

1. Introduction

The Aral Sea is a partly freezing, drainless lake located in the deserts of Central Asia. Its level fluctuated during the Pleistocene-Holocene history, but in the second part of the XX century it dropped dramatically due to the human impact. Using satellite images, we found landforms of ice-ground interaction on the exposed bottom of the Aral Sea (Maznev et al., 2019). Nevertheless, the age of these landforms is currently unknown. Therefore, the study aimed to reconstruct the evolution of the ice gouging processes and landforms during the second part of the XX – beginning of the XXI centuries.

2. Materials and methods

To study the exposed topography on the vast territory of the former bottom, we used satellite images of ultra-high resolution from public sources Yandex.Maps (<https://yandex.ru/maps>), Google Maps (<https://www.google.ru/maps>), Bing Maps (<https://www.bing.com/maps>), ESRI World Imagery (<https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08feb2a9>) derived from satellites WorldView, QuickBird, IKONOS and GeoEye of Maxar Technologies Company.

We estimated the age of the scours, compared ice gouging conditions and defined factors influencing the localization of different intensities of effects in this work. We used a complex of analytical approaches including the historical-genetic method, comparative geographical analysis and others. We supposed that the zone of the most intensive ice gouging was located at a depth of 2-5 m by the analogy with the Caspian

Sea (Ogorodov et al., 2020). For reconstruction of ice-gouging topography evolution, we examined the intersections of certain scours with paleocoastlines. The ancient coastlines are known from satellite images deciphering (Kravtsova and Tarasenko, 2010). In this way, we have a depth of the ice gouging event that happened in a year(s) when the Aral Sea level was 2-5 m higher. We analyzed many such intersections in different parts of the Aral Sea to reconstruct events for several time intervals.

3. Results and discussion

We suppose that exposed ice-gouging topography was formed at the last stage of the bottom evolution, immediately before and during the degradation of the Aral Sea. A similar topography was formed during the Pleistocene-Holocene in epochs with similar climatic conditions. Under various conditions, from the Arctic to the subtropics, the ice-gouging microrelief can persist for different times depending on local conditions (Maznev and Ogorodov, 2020). At the Aral seabed due to sedimentation and other lithodynamic processes such a topography could not be preserved at the bottom for a long time. Thus, these landforms refer to the second half of the 20th century when the level of the Aral Sea began to fall.

In 1960, before the level dropped, the ice ridges affected most intensively the coastal parts of the Aral Sea and the area of the central rise. Now, we see the most significant number of the scours are located at depths of 15–25 m relative to the 1960 level. Probably, they were formed when the sea depth was 2–5 m in these areas. By that time, the sea level had fallen by 10-20 m and was about 33-43 m a.s.l. Such a level in

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the South Aral Sea was observed from the early 1980s to the early 2000s.

During the level drop, the zone of the most intense ice impacts and, accordingly, ice scours formation shifted along with the coastline. These zones gradually moved to the middle of the Eastern and Western Aral and then merged in the central part of the basin.

The scours concentrate mainly not in the central and deepest part of the water area but near the 1996-2002 coastline. The most intense ice gouging zone came here from the east coast in the late 1980s – mid-1990s.

Thus, we assume the following reconstruction of the ice-gouging topography formation at the Aral seabed. Until the early 1970s, the level fall was not fast enough to change ice processes. The scours did not preserve for several years; they were washed out and covered with sediment. Scours of this age are almost not present in modern topography. From the beginning of the 1970s, the level drop rate increased, and the newly formed scours did not fill with sediments. As a result, areas with a relatively high concentration of ice scours were formed. Since the mid-1980s, the shrinking of the water area and the decrease in the heat content made the ice conditions severer. At this time, the main mass of ice scours formed. In the 1980s – 1990s, ice scours formed in areas framing the central part of the Eastern Aral from all sides. By the end of the 1980s – mid-1990s, the zone of the most intense ice effect, shifting from the eastern and western shores of the Eastern Aral, reached its central part. At that moment, the conditions for the formation and preservation of the ice-gouging topography on the seabed were the most favorable. The ice scours were forming on vast areas of the flat bottom of the central Aral Sea basin with 10 m depths (at the beginning of the period). Ice conditions during that period were still relatively severe, while weak hydrodynamic activity in the shallow water area led to the good preservation of landforms. From the mid-1990s to the mid-2000s, the intensity of ice impacts decreased. In the late 2000s, the waters of the Eastern Aral became hypersaline, ice formation became fragmented, the reduced area of the reservoir prevented ice ridging, and the gouging almost stopped.

The period of the 1980s-1990s is highlighted by the highest intensity of ice impacts when drifting ice could affect the most extensive areas of the bottom.

Conversely, the period of the 1960s is characterized by the least intensity when stable fast ice protected the coastal zone from effects. Such a timescale of impacts reflects the age distribution of ice-gouging landforms at the Aral seabed.

4. Conclusions

The ice scours on the former bottom of the Aral Sea are a geomorphological relic due to the unique conditions in the disappearing sea. The level drop led to ice impacts acting almost overall former water area. At the same time, the reworking of the upper part of the sediments over a large area of the former bottom shows that such processes should be considered in paleolimnological studies in lakes with fluctuating levels. In all freezing water bodies at shallow depths, sedimentary layering can be disturbed, sediments can be mixed, which complicates the reconstruction of paleolimnological events.

Conflict of interest

The author declares no conflict of interest.

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Cryptotephra of Lake Khorlaket (Northern Caucasus, Russia)

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ABSTRACT. A tephrochronological study of the core HOR-1 of bottom sediment from Lake Khorlaket, located 24 km northwest of the Elbrus summit, was carried out. The core was 253 cm length. Deposits are represented by interbedding of thin-layered loams and bio-mineral silt. Six intervals of increased content of cryptotephra from 37,000 to 111,000 shards g dry weight⁻¹ were identified. For a prominent peak of cryptotephra concentration in 214-215 cm, which is hardly noticeable as a whitish layer in the core, a geochemical relationship has been established with the proximal tephra of the Elbrus volcano. The age of this peak is estimated at 5950-6250 cal. yr BP.

Keywords: tephra, tephrochronology, cryptotephra, Lake Khorlaket, volcanic ash

1. Introduction

Within the Greater Caucasus Range, active eruptive centers are located. They are represented by the grandiose edifices of the Elbrus (5642 m a.s.l) and Kazbek (5047 m a.s.l) volcanoes and a group of monogenic volcanoes of the Kely Highland. These centers were repeatedly active during the Late Pleistocene – Holocene, and that is why they can resume their eruptions and constitute a danger to the densely populated southern regions of Russia and adjacent countries. To develop a long-term forecast of volcanic activity in the region, it is necessary to reconstruct in detail the regime of volcanic activity over the past thousand years.

The existing data about Late Pleistocene-Holocene volcanic activity within the Greater Caucasus Range are based mainly on lavas' study (Lebedev et al., 2010; 2011; 2018). These studies identified the main stages in Elbrus, Kazbek, and the Kely Highland volcanic centers activities. According to these authors, the last phases of activity began on Elbrus <35,000 years ago, Kazbek <50,000 years ago, and on the Kely Highland <30,000 years ago. However, information about the products of recent explosive activity is exceptionally scarce (Bogatikov et al., 1998; Gazeev et al., 2011). Radiocarbon dates obtained in different sections from

bulk samples of coals and paleosols allowed to estimate roughly the age of several Elbrus tephra (7200-7500, 4600-5500, and ~2000 years ago) and two lahars in the valley of the Baksan River (7200 and 5800-6000 years ago), which are possibly related to the Elbrus eruptions (Bogatikov et al., 1998). Holocene scorias and pumices are mentioned in the Kely Highland, but their age is unknown (Gazeev et al., 2011; Lebedev et al., 2011). Deciphering the detailed history of young explosive eruptions in the region is hampered by the poor preservation of tephra horizons in high mountains due to intense erosion.

To obtain a complete record of the Caucasian volcanoes eruptions, we undertook the study of the lake sedimentary archive. This work aims to search for tephra and cryptotephra horizons, i.e., sediment horizons enriched in ash material. In such studies, along with ashes from local volcanoes, ashes from very distant sources can also be identified (Davies, 2015). Since tephra fallout occurs almost instantly, its layer forms an isochrone, which allows to correlate remote sections directly. This correlation is based on the uniqueness of the chemical composition of volcanic ash for each eruption. Small lakes and peatlands represent the most complete and continuous paleo-archives of the Holocene in the Caucasus. Due to constant sedimentation and lack of erosion, they preserve a

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more comprehensive and detailed record of explosive volcanic eruptions than the soil-pyroclastic cover of volcano foothills.

So far, only a few studies of cryptotephra have been carried out on the territory of the European part of Russia, which made it possible to detect several Icelandic tephra in the north of the European part (Haflidason et al., 2019; Vakhrameeva et al., 2020; Wastegård et al., 2000). The studies of the Holocene cryptotephra in the North Caucasus have not been carried out early.

2. Materials and methods

Lake Khorlaket (N 43.493145, E 42.218746) is located in the mountains of the Karachay-Cherkessia on the slope of the Front Range in the interfluvium of the Khudes and Khurzuk Rivers at an altitude of 2040 m a.s.l. and 24 km to the northwest from the western peak of the Elbrus volcano. The core from Lake Khorlaket is 2.5 m length, and was sampled during the expedition of the Institute of Geography of the Russian Academy of Sciences in 2017. We ^{14}C dated 12 samples from this core. According to the data, these samples were formed during 1000-8000 cal. yr BP.

The search for cryptotephra horizons was carried out according to S.M. Davies (2015) and S.P.E. Blockley et al. (2005). Thus, continuous channel samples 10 cm long were taken from the core to detect cryptotephra. The material was dried, and its dry weight was determined. Next, dry samples were treated with 20% H_2O_2 to remove organic matter and washed in a 25 μm sieve. With the help of density separation, a light "rhyolite" fraction (2.3–2.5 g/cm³) and a heavy "basalt" fraction (>2.5 g/cm³) were separated by the heavy HPS-V liquid. A glass microscope slides in Canada balsam was made from the obtained sediment of the "rhyolite" fraction. Using a polarizing microscope with a magnification of 100-400x, identification was made among the particles of the light fraction of volcanic glass based on their specific properties: shape, structure, optical isotropy, relative refractive index, and color.

At the Shirshov Institute of Oceanology of RAS, a high-resolution core scan was also carried out using a Geotek scanner. As a result, additional lithological characteristics were obtained - magnetic susceptibility, color, and chemical composition.

For a sample from a depth of 213-223 cm, which has high volcanic glass content, a slide in the epoxy resin was made, and microprobe analysis of ash particles (EMPA) was carried out at the GEOMAR Institute (Kiel, Germany).

3. Results and discussion

The study of glass microscope slides with a "rhyolite" fraction showed that in the sediment, along with small volcanic glasses (30-50 μm), there are also large (up to 300 μm) pumiceous and composite particles (scorias), which, along with glass, include many microcrystals in their structure. The concentration of volcanic particles varies along the core from 75 shards

g dry weight⁻¹ to very high values – 111,000 shards g dry weight⁻¹. Concentration peaks fall within the intervals: 10-20 cm (> 37,000 shards g dry weight⁻¹, 1406-2259 cal. yr BP), 50-60 cm (> 37,000 shards g dry weight⁻¹, 2972-3498 cal. yr BP), 193-203 (> 111,000 shards g dry weight⁻¹, 5108-5854 cal. yr BP), 203-213 cm (>68,000 shards g dry weight⁻¹, 5375-6116 cal. yr BP), 213-223 cm (> 35,000 shards g dry weight⁻¹, 5923-6475 cal. yr BP).

According to the results of core scanning, an interval of 205-215 cm was revealed, which has increased magnetic susceptibility values. Furthermore, according to the photos obtained from the scanner, light layers are also distinguished at depths of 205-207 cm and 213-214 cm.

According to the calculation of cryptotephra, peak concentrations are observed in the intervals of 193-203 cm (5108-5854 cal. yr BP), 203-213 cm (5375-6116 cal. yr BP) and 213-223 cm (5923-6475 cal. yr BP). Moreover, the largest tephra particles (150-300 μm) predominate in the lower interval. Based on the data obtained, we assume that the interval of 213–214 cm with a high probability corresponds to the eruption. The overlying interval (193–213 cm), enriched in volcanic ash, probably formed as a result of secondary redeposition of tephra particles due to washout from the adjacent watershed.

Chemical analyzes of volcanic particles from slide 213-223 cm showed that they are represented by fragments of porous rocks, which contain high-silica glasses, similar in composition to the Holocene tephra of Elbrus. This tephra is a product of the crushing of a viscous lava dome.

4. Conclusions

The study of the bottom sediments of Lake Khorlaket revealed a high content of cryptotephra in the deposits. The interval 193-215 cm with very high content of cryptotephra stands out in particular. Therefore, we assume that the bottom of this interval (214-215 cm) corresponds to the largest eruption of the Elbrus volcano in the Holocene. According to a sediment growth model based on a series of radiocarbon dates, the age of this eruption is estimated at 5950-6250 cal. yr BP.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.

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Identification of the dynamics of carbon accumulation in the Verkh-Invenskoe peatland by the method of Loss on Ignition



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ABSTRACT. The Perm Kama region is characterized by numerous promising paleoarchives, and the paleoecological knowledge of the region is uneven. Identification of the dynamics of organic carbon accumulation in peat is included in the complex of studies used to reconstruct the state of the natural environment in the past. We have studied peat deposits of the Verkh-Invenskoe bog in the western part of the region. For this, depth measurements, sampling of a peat column, and laboratory analysis of samples throughout the thickness were performed. As a result, indicators were determined: Bulk Density (further – BD), Organic Matter Bulk Density (further – OMBD), Loss on Ignition (further – LOI), Long term average rate of carbon accumulation (LORCA). For the first time for the western part of the Perm Kama region, numerical data on the dynamics of carbon accumulation over the last 10.9 thousand years have been obtained.

Keywords: carbon, peatland, LORCA, LOI, paleoecology, Perm Kama region

1. Introduction

Paleoecological knowledge of the Perm Kama region is quite uneven. The region of the Upper Kama (from the village of Tyulkino to the village of Gainy) has been studied better than others. Dedyukhinsky Island and the adjacent area of the Chashkinsky Lakes should also be considered a well-studied area. At the present stage, several paleoarchives have been studied in detail in the southern part of the region: the Kungur forest-steppe, the region of mixed coniferous-deciduous forests and the environs of the city of Perm (Mekhonoshina et al., 2022). The western part of the Perm Kama region still remains practically unexplored. A promising paleoarchive for this part of the region should be considered the Verkh-Invenskoe bog.

The bog is located in the Kudymkarsky municipal district, its area is about 110 hectares. The Inva River flows along the eastern border, and its left tributary, the Vezhayka River, flows from the north.

2. Materials and methods

With the help of remote sensing data, vectorization of the swamp contour was carried out. The places for measuring the depth of the peat deposit were determined on a regular grid with a step of 150 m. The thickness of the peat layer was measured with

a peat probe, which was immersed in the ground as far as possible - until it stops.

A point was chosen for the selection of a peat column, where the depth of the peat deposit turned out to be the greatest.

Drilling was carried out using a peat (Russian) drill. In total, 11 cores of 50 cm each were selected and described. At the same time, peat lay down to the level of 470 cm. Deeper, a homogeneous mineral layer composed of gray-blue clays was noted.

Further, the content of organic matter was determined by the loss on ignition method (Chambers et al., 2010) along the entire profile of the column. The essence of the method consists in ashing (calcining) peat samples in a muffle furnace at a temperature of 550 °C. A total of 460 peat samples were processed. The following indicators were calculated: BD (g cm⁻³), OMBD (g OM cm⁻³), LOI (g), LOI (%), organic carbon (%). Long term average rate of carbon accumulation was calculated using average values of carbon content differentiated by peat types (Loisel et al., 2014).

To date, the age of the peat sample from a depth of 462-464 cm has been determined by the AMS method. The analysis was carried out in the Poznan Radiocarbon Laboratory. The result of radiocarbon analysis of sample Poz-146486 is 9550 ± 50 ¹⁴C BP. This corresponds to the age of 10,9 kyr cal. BP. Calibration was performed using the Calib 8.2 online service

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(Stuiver et al., 2021) using the IntCal20 calibration curve (Reimer et al., 2020). Based on the available sample date from the base of the column, the LORCA score is calculated.

In addition, a hypothesis was put forward about the possible flooding of the swamp area by a nearby stream during floods. For this, a profile of the Inva river valley was constructed, passing through the sampling point of the core. According to the hydrological post in the city of Kudymkar, the level of high waters (HWL) was determined.

3. Results

On the graph of the content of organic carbon relative to the depth of the column, 9 zones are distinguished (Fig.).

The average organic content (LOI) for the entire column is 89.28%. The minimum and maximum values for the column are 11.90% (469-470 cm) and 99.30% (355-356 cm), respectively.

The average content of organic carbon is 43.65%. The minimum value is 5.95% (469-470 cm), the maximum is 50.39% (244-245 cm). Areas of increase and decrease in the percentage of organic carbon correlate with areas of increase and decrease in the percentage of organic matter throughout almost the entire depth of the column.

469 cm. The minimum value of the content of organic matter and carbon is noted – 5.95%.

467-447 cm. From a depth of 467 cm there is a sharp increase in values from 22.64% to 35%, continuing to a depth of 460 cm. Then there is an abrupt decrease in carbon (up to 29.2%) up to a depth of 455 cm, with a subsequent increase in values up to 49.1% at a depth of 447 cm. The average carbon concentration throughout the entire area is 32.8%.

447-423 cm. There is a decrease in values to 44.1% at a depth of 423 cm. The average value of the indicator is 46.8%.

423-393 cm. The zone is characterized by sharp jumps in the carbon content throughout its length with a maximum amplitude of up to 15%. The average carbon content is 43.2%.

393-218 cm. The values of this zone are rather homogeneous. The average percentage of carbon in this segment is 46.4%, which is higher than the average value for the entire column.

218-207 cm. At the site, the carbon concentration is uniform, but significantly lower than the previous and subsequent layers of peat with an average content of 39.9%.

207-40 cm. The average concentration of carbon again rises to 44.8%, the values of the indicator in this zone are characterized as homogeneous.

40-10 cm. On the site, fluctuations in the values of the indicator are observed from the minimum – 39.7% to the maximum – 46.9%.

10-0 cm. 10-0 cm. The values of the indicator are not available, since there was not enough material for analysis in this area of the peat column.

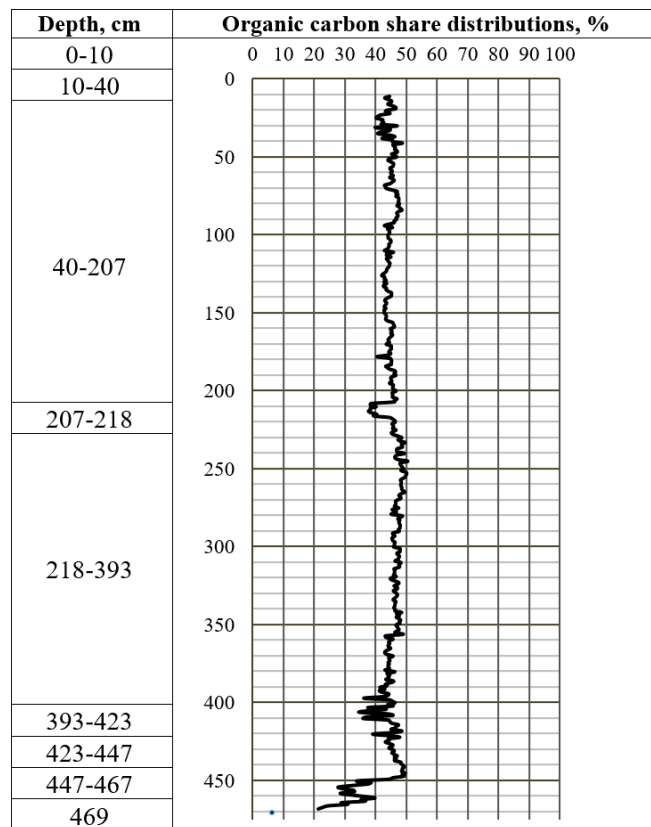


Fig. Distribution of organic carbon content

The curve of the content of organic carbon in the peat of the Verkh-Invenskoe bog remains at the same level over most of the core or fluctuates slightly. Several areas where sharp fluctuations were found are at the base of the column and its upper part.

Long term average rate of carbon accumulation (LORCA) was 26.43 g/m²/year, with a total carbon mass (over the entire column) of 28.83 g.

4. Discussion and conclusions

The age of the base of the peat bog indicates that the formation of the bog began at the end of the preboreal period.

A significant difference in the content of organic carbon at depths of 469 cm and 467 cm is explained by the transition of sapropel deposits to peat, which was shown by a preliminary microscopic analysis of peat. In the area of 467-423 cm, fluctuations in the carbon concentration fall on the process of bog formation.

Subsequent fluctuations of the indicator, noted in the interval of 423-393 cm, are apparently associated with the introduction of minerals due to periodic flooding of the site during floods. The constructed profile of the valley of the river Inva indicates that the maximum level of high waters of the river could reach a depth of 320 cm of peat bog.

The homogeneity of the distribution of the values of the indicator in the interval 393-40 cm indicates a long-term development of the bog according to the transitional type, since there is no obvious decrease or increase in the content of mineral substances.

The fluctuations noted at a depth of 40-10 cm appear to be related to the accidental introduction of foreign clay in the sampler tube.

The study of the Verkh-Invenskoe bog peat column made it possible for the first time, for the western part of the Perm Kama region, to obtain numerical data on the dynamics of carbon accumulation over the last 10.9 kyr.

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Conflict of interest

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Lake Chistoye (northern Priokhotsk area, Russia) – the high resolution environmental archive for the Holocene

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ABSTRACT. Lake Chistoye in northeastern Russia provides one of the longest sequences of the Holocene sediments. Bottom surface and core sediments were analyzed using the complex method including rock magnetic, paleomagnetic, geochemical, mineralogical and radiocarbon dating. Two layers tephra with distinct individual petrophysical, geochemical and mineralogical characteristics were distinguished in the sediments. High-resolution secular variations of the geomagnetic field were constructed from the cores. According to radiocarbon dates, the lake was formed since the beginning of the Early Holocene. Synchronously, near the lake began an accumulation of marsh peats.

Keywords: Lake Chistoye, Holocene, rock magnetism, geochemistry, lake sediments, tephra

1. Introduction

Lakes of the North-East of Russia have different origins, age, physical and hydrological parameters, elevation, and composition of the surrounding rocks. Lakes of glacial, thermokarst, and tectonic origin are widespread in the continental part of the territory. The age of most lakes is relatively young and is limited by the end of the Pleistocene–the beginning of the Holocene. Lakes El'gygytyn (67°30' N; 172°05' E.) and Grand (60°44' N, 151°53' E) are among the ancient lakes, whose sediments began to form in the Late Pliocene (3.6 Ma) and the Late Pleistocene (60 ka), respectively (Melles et al., 2012; Minyuk and Subbotnikova, 2021). The lakes are differed rates of sedimentation and sediment composition. The thickness of Holocene sediments varies from several tens of centimeters to several meters. Among the studies lakes the maximum thickness of Holocene sediments is in Lake Chistoye (945 cm). The sediments from this lake are a unique material for obtaining detailed data about changes in the Holocene environment.

2. Materials and methods

Lake Chistoye (59.543850 °N, 151.800185 °E) is one of the largest in the Northeast. Its length is 8.8 km, width – 6.5 km, maximum depth – 6.6 m (Fig.). About 30 tributaries with various lengths inflow into the lake. The lake is located in the Lankov Cenozoic depression of the Northern Priokhotye, on the left bank of the

Lankovaya River (a tributary of the Ola River). The depression is filled by Cenozoic sediments. Holocene marsh peats containing layers of tephra are common on the southern and northern shores. The eastern, southern and western hills surrounding the lake are composed of basalts, andesites and their tuffs of the Lower Cretaceous P'yagin formation. Late Cretaceous tuffs of acid composition, tuff sandstones are located in the north of the lake. Chemical and physical weathering products from these rocks comprise the majority of the clastic deposits in the lake.

Nine sediment cores were sampled during winter from 2016 to the present.

The core sediments were split into 1-cm segments (945 samples) for various types of analyses, including petrophysical, mineralogical, geochemical, granulometric, palynological and diatomic. The organic matter was selected for radiocarbon dating. The sediments from the longest core 9 and 6 were continuously sampled for paleomagnetic investigations with plastic boxes 2 × 2 × 2 cm; yielding a collection of 439 and 286 specimens, respectively.

3. Results and discussion

The lake water is ultra-fresh with total mineralization 32.15–53.76 mg/l, total hardness is 0.14–0.46 mg-eq/l, pH = 4.8–6.6.

Surface sediments

In summer 2021, a set of 71 surface sediment samples was collected from the floor of Lake Chistoye.

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The surface sediments of lake consist of gravel, sand and silt (clay). The spatial distribution of the sediments shows coarse-grained material in the western and southern edges of the lake whereas silt is dominated in the central and eastern parts of the lake.

Geochemical and petrophysical parameters of sediments were followed the lithology. In the western part, where sand is dominant, sediments are more magnetic, also increased values of magnetic (MS) saturation magnetization (Js) and remanent saturation magnetization (Jrs). Hysteresis data of the silt sediments shows a finer magnetic granulometry.

According to geochemical data, the coarse-grained sediments are less chemically altered. They are enriched with mobile elements – SiO_2 , Na_2O , CaO , K_2O . Silt and clay shows the high content of Al_2O_3 , Fe_2O_3 , MgO , and TiO_2 .

Magnetic minerals are represented by a wide range of titanomagnetites with a titanium content from several percent to 26%. The Curie points of magnetic minerals range from 540–580°C (low-titanium titanomagnetites) to 100°C (high-titanium titanomagnetites). Typical impurities are manganese, silicon, aluminum, chromium.

Grains of titanomagnetites have abundant shrinkage cracks, which provide clear evidence for low-temperature oxidation (maghemitization). Maghemite (titanomaghemite) is fixed on thermomagnetic curves during its transition to hematite at T 400–425°C. Some heating curves show an increasing magnetic susceptibility at T = 235–254°C, followed by a decrease during further heating to 580 °C indicating the transformation of lepidocrocite into maghemite–hematite (Gehring and Hofmeister, 1994; Gendler et al., 2005). Thus, surface sediments data have a direct impact on the interpretation of the environmental record derived from sediment cores of Lake Chistoye.

Core sediments

The core sediments are mainly consist of silt and clay. Sand and gravel deposits are located at the base of the cores. The sediments thickness is 577 cm (core 1), 599 cm (core 2), 223 cm (core 5), 635 cm (core 6), 945 cm (core 7). Two tephra layers with distinct individual petrophysical, geochemical and mineralogical characteristic are found in the sections. The lower tephra (KO) is acidic composition, weakly magnetic, and is correlated with the tephra of the Kuril Lake caldera in Kamchatka, which is 7,600 years old (Ponomareva et al., 2004). According to the mineralogical data of 29 grains, two groups of titanomagnetites are clearly distinguished in magnetic extract from tephra. The group of high-titanium titanomagnetites shows the titanium content between 24.26–28.01 wt% (average 25.54 wt %). In the second group of titanomagnetites, titanium concentrations are 0.35–16.87 wt% (average 6.48 wt%).

KO tephra are found at depths of 373–377 cm (core 1), 360–364 cm (core 2), 190–193 cm (core 4), 185–189 cm (core 4a), 184–188 cm (core 4b), 182–186 cm (core 4b), 433–435 cm (core 6), 625.5–626.5 cm (core 7).

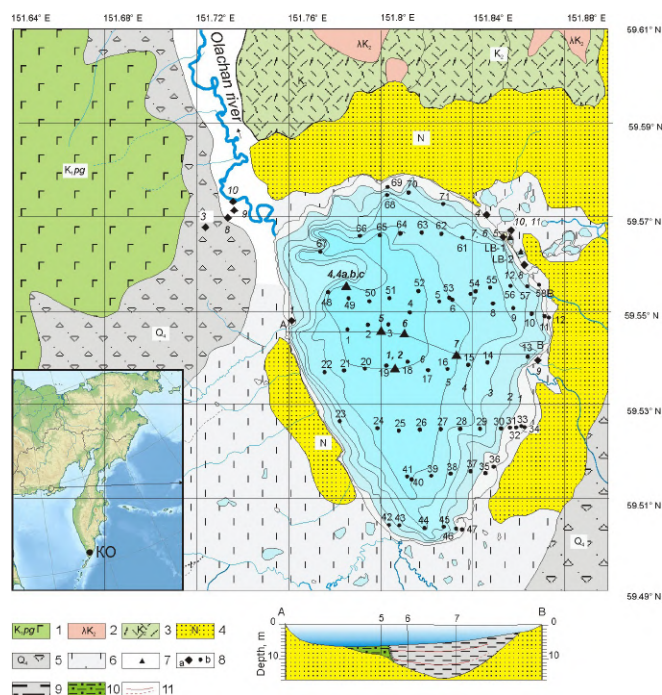


Fig. Location, geological map of the Chistoye Lake area and cross-section of the lake. 1 – Lower Cretaceous P'yagin formation; 2 – Upper Cretaceous intrusive; 3 – Upper Cretaceous volcanic rocks; 4 – Neogene sediments; 5 – slope sediments; 6 – Holocene marsh peat; 7 – core sites; 8 – slope sediments sites (a) and surface bottom samples (b); 9 – silt lake sediments; 10 – sand lake sediments; 11 – tephra depth based on core measurements; KO – Kurile Lake caldera.

The upper tephra was recognized at depths of 86–88 cm (core 1), 77–80 cm (core 2), 36–38.5 cm (core 4), 35.5–37 cm (core 4a), 31–34 cm (core 4b), 36.5–37 cm (core 4b), 162.0–166.0 cm (core 6), 237.0–249.0 cm (core 7). Visually, tephra is difficult to find in the sediments, but can be easily distinguished by the maximum values of magnetic susceptibility. The shards have in average SiO_2 content of 64.65 wt%, the sum of $\text{K}_2\text{O} + \text{Na}_2\text{O}$ is 7.57 wt% in average, indicating the dacite composition.

Magnetic minerals of the upper tephra, according to the study of 28 grains, are composed of low-titanium magnetites with an average titanium content of 2.7 wt%. Vivianite is found everywhere along the sections in the sediments of the lake.

The radiocarbon age of organic matter from core 1 is 8815 ± 36 years (depth 524 cm) and 5349 ± 33 years (depth 266 cm). Based on the radiocarbon dates and assuming that the sedimentation rates are approximately the same in the core the interpolated age of the upper tephra is 1350–1590 years in the core 1. The sediments of the lake include diatoms, organic remains their study will allow reconstructing the natural environment of the Holocene. The petromagnetic parameters of sediments vary significantly along sections, reflecting changes in sedimentation conditions. The values of magnetic susceptibility in core 7 are $(-0.4-1.8) \times 10^{-6} \text{ m}^3/\text{kg}$ (average = 0.4). Magnetic susceptibility, hysteresis parameters and the tephra layers are used as tools for the correlation between different sediment cores. The

shift of petromagnetic characteristics is at 500 cm in the longest core 7. High-resolution secular variations of the geomagnetic field were constructed from the core 6 and 7. Cores 7 and 6 were correlated using both secular variations and rock magnetic features and can be correlated with the Holocene secular variation records from the other regions.

The maximal sedimentation rate is in core 7, where they are approximately 1 cm/10 years. According to radiocarbon dates, the lake was formed since the beginning of the Early Holocene. Synchronously, near the lake began an accumulation of marsh peat having a radiocarbon age of 9725 ± 250 years.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Paleoclimatic conditions of a Late Pleistocene mega-lake in Kamchatka

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ABSTRACT. Here we present the pollen spectra of the Central Kamchatka depression from 28.4 to 7.9 ka. Our study is based on a key lacustrine section Kamplen that deposited in a Late Pleistocene mega-lake and thus represents an integral peninsula-scale record. Pollen analysis allows us to identify seven local pollen zones reflecting the main stages of vegetation and climate change.

Keywords: Kamchatka, Pleistocene, pollen analysis, mega-lake

1. Introduction

The Kamchatka Peninsula is a home of the very active landscapes, being transformed by both volcanism and tectonics; global climatic changes affect Kamchatka as well. However, Late Pleistocene history of Kamchatka remains unclear due to scarcity of datable material in studied disparate sedimentary sections. Our recent studies (Ponomareva et al., 2021) allowed us to create a tephrochronological framework that tied together and dated a number of lacustrine sections across the Central Kamchatka depression (CKD, Fig.). These findings suggest the existence of a mega-lake covered most of the CKD, as neither topography nor glaciers were sufficient barriers to isolate separate basins. In this study, we present a robust paleoclimatic reconstruction throughout the existence of the mega-lake.

2. Materials and methods

Climatic reconstructions are based on the pollen analysis of the Kamplen section (Ponomareva et al., 2021), a Late Pleistocene lacustrine section with accurate AMS 14C age control. It is located to the north of the Klyuchevskoy volcano in the coastal cliff of Klyuchevskoe Lake (Fig.). Pollen preparation followed standard procedures for glycerine samples (Moore et al., 1991) processed at Lakehead University Orillia (Canada) laboratory. AMS radiocarbon age estimates are based on the age model published in the work of V.V. Ponomareva and co-authors (2021).

The section Kamplen includes light fawn silty loams with frequent horizontal layers of volcanic ash

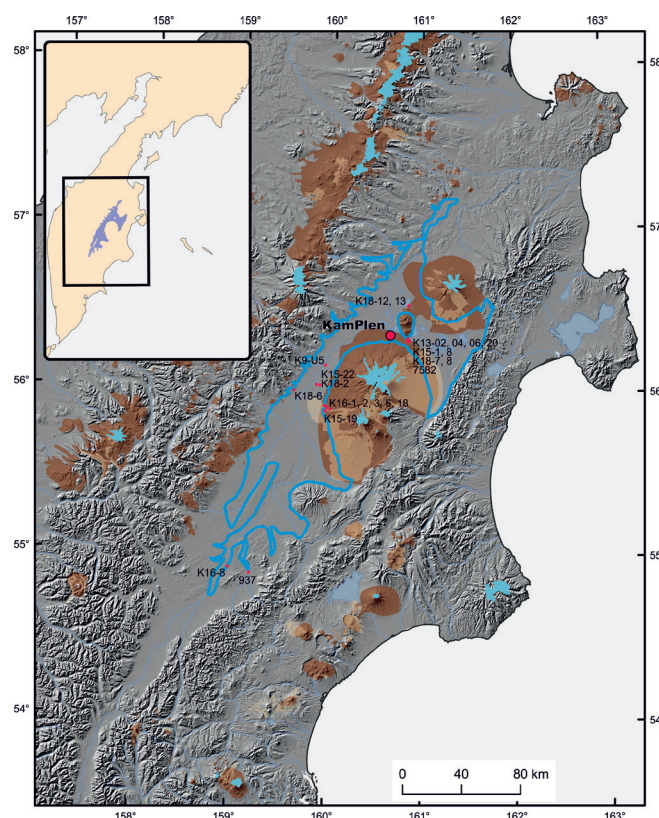


Fig. Location map after Ponomareva et al. (2021) showing studied sections (red circles, Kamplen key site labelled in bold), and suggested extent of the CKD lake basin (blue outline in the figure and blue shade in the inset). Modern glaciers are shown in turquoise, Holocene volcanic deposits including debris fans are in light brown, Late Pleistocene volcanic deposits are in dark brown.

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with a thickness of 0.5 to 4 cm. In the upper part they are covered by a soil-pyroclastic material. The depth was calculated not from the surface, but from the bottom of the eruption of the Khangar volcano tephra (KHG), which is widespread in the region and dates from 7872 ± 50 yr (Cook et al., 2018).

3. Results and discussion

Pollen analysis allows us to identify seven local pollen zones reflecting the main stages of vegetation and climate change.

Stage **28.4-25.3 ka** marks the beginning of cooling during the transition from MIS 3 to MIS 2. It is characterized by a low content of tree pollen, the dominance of shrub pollen in the group of trees and shrubs, and the predominance of grass pollen. The climate was mild and humid, but not as mild as today. This contributed to the spread of shrubby tundra and subalpine meadows with rocky unvegetated areas. The areas of spruce, birch and poplar forests were small.

Stage **24.6–21.0 ka**: the progressive cooling of the climate continued. The pollen diagram shows the increase in the proportion of dwarf pine (*Pinus pumila*), dwarf birch (*Betula* sect. *Nanae*) and willow (*Salix*) pollen. In addition, pollen of plants that tolerates cold climate appears. So the vegetation cover in the north of the CKD was dominated by grass-mixed alpine meadows, and the forest area was reduced.

Stage **21.0-18.0 ka** corresponds to the peak LGM cooling. It was characterized by sparse vegetation, similar to modern high-altitude wastelands. Only plants capable of withstanding harsh climatic conditions could grow so close to the edge of the glacier: *Koenigia*, *Dryas*, *Ranunculus nivalis*, typical for high-altitude plant communities of the region. The stages 21.0 to 18.0 ka are characterized by a high taxonomic diversity of pollen without obvious dominants and low pollen concentration. I.F. Pendea et al. (2017) got similar results according to pollen analysis of Krutoberegovo section (east coast of Kamchatka peninsula). High taxonomical diversity they interpreted as signal of cold and dry climate.

Stage **18.0-12.5 ka**. Pollen of cereals (Poaceae) sharply prevails in the spectra, pollen of Cyperaceae and Ranunculaceae is also relatively numerous. At the same time, there is very little pollen of trees and shrubs. Taxonomic diversity stays high and concentration is still low. This may be evidence of the ongoing continentalization of the climate which becomes maximum from 14.5 to 12.5 ka. Phytocenoses similar to tundra-steppe ones spread in the Central Kamchatka depression.

Stage **12.8 – 11.6 ka**. This stage is characterised by a sharp increase in the proportion of shrubby alder (*Alnus fruticosa*) in the composition of pollen spectra, which can serve as a sign of the expansion of subalpine phytocenoses, currently represented mainly by shrubby alder and mountain pine thickets. Similar changes in the pollen spectra about 11.6 ka are recorded by many researchers of Western Beringia. An increase of

shrubby forms of alder and birch pollen is noted in the Krutoberegovo section (Pendea et al., 2017), and in other sections of the eastern coast of Kamchatka and the entire north of the Russian Far East (Edwards et al., 2005). Apparently the response of vegetation to climate warming was very rapid.

Stage **11.6 – 7.9 ka**. In the pollen spectra, an increase in the amount of *Alnus fruticosa* as well as *A. fruticosa* pollen is noticeable. In addition, at this time, the proportion of spores in the pollen spectra increases, mainly due to the spores of ferns from the Polypodiaceae. After 11.6 ka, during the transition to the Holocene, the climate became warmer and wetter, and as a result moisture-loving river-coastal and floodplain forests of poplar (*Populus*) and downy alder (*A. fruticosa*) spread in the CKD.

The sediments of the Kamplen section dated back to 28.4 to 11.6 ka contain pollen of aquatic plants, in particular such taxa as *Potamogeton*, *Callitriche*, *Nymphaea*, *Nuphar* and others. In addition, 11.6 ka BP, the nature of sedimentation changes and the soil-pyroclastic cover begins to accumulate. We assume that this indicates the lacustrine genesis of the Kamplen section deposits. It also indirectly indicates precisely the shallow depth of the reservoir, since pollen of aquatic plants attached to the bottom of the reservoir is found in deposits. The border of 11.6 ka marks the time of the giant lake draining.

4. Conclusions

The pollen analysis of the Kamplen section, which is the most accurately dated Late Pleistocene sedimentary record from Kamchatka Peninsula (Russian Far East), permitted us to date seven local pollen zones reflecting ecological changes in Kamchatka in the time range from 28.4 to 7.9 ka.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Diatoms of the Aleutian Islands (Alaska, USA) in the Holocene

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ABSTRACT. Here presented a short overview of paleoreconstruction works started since 2018 for the Aleutian Islands region. Material is from four Aleutian Islands that represented by peat deposits and modern waterbodies samples are studied. Modern and fossil diatom communities of these islands are described, diatom analyses and paleoreconstructions are performed.

Keywords: the Aleutian Islands, Alaska, the Holocene, diatoms, paleoreconstruction, peat sediments

1. Introduction

Diatoms are well known to be a good and sensitive bioindicators. The valves of diatoms are well preserved in the bottom sediments of marine and continental waterbodies. These features of diatoms allow to apply the data on the species composition of bottom or peat sediments to reconstruction of the environmental conditions at certain points in time in the past and to reconstruct the changes in the intervals between them (Battarbee, 1984; Reid et al., 1995).

The region of Aleutian Ridge is a region with complex geological and climatic history and is of interest for different paleoreconstructions. Diatom flora of the Aleutian Islands, both modern and fossil, represented by fragmentary data for some waterbodies on particular islands. Despite the fact that the study of diatoms in mainland Alaska and some islands of the Aleutian Ridge dates back more than 100 years, in general, this group of algae is insufficiently studied in this region (Saunders, 1901; Patric and Freese, 1960; Foged, 1981; Hein, 1990; Bahls and Luna, 2018). A comprehensive study describing the species diversity of both the diatoms of modern waterbodies and the Holocene ones has not been conducted. This work, beginning since 2018 as a PhD thesis, is aimed to trace the dynamics of the diatom communities on the Aleutian Islands during the Holocene and to identify its relationship with local and global environmental changes in the region. The main objectives of this work are: to study the taxonomic composition of diatoms of modern waterbodies and Holocene peat deposits on several islands; to reconstruct developmental stages of five waterbodies on four islands in the Holocene using diatom analysis; to check the correlation in time

of such changes and identify their relationship with local changes in paleoenvironments and global climatic changes in the region.

2. Material and methods

The Aleutian Islands (USA) are the archipelago in the North Pacific Ocean of volcanic origin, divided into 6 large groups of islands, which extend in an arc from the coast of the Alaska Peninsula (USA) to the base of the Kamchatka Peninsula (Russia) (Fig.).

Material from four different Aleutian Islands (Table) was used in this study. The material was collected by A.B. Savinetsky and his colleagues (A.N. Severtsov Institute of Ecology and Evolution RAS) in 1997-2018 on Adak, Carlisle, Shemya and Unalaska Island. For all peat sediments radiocarbon data has been obtained. Samples are prepared according to standard methods and studied by light and studied using light and scanning electron microscopic methods. Diatom analysis is performed for Shemya Island and Carlisle Island peat sediments.

3. Results and discussion

Total 253 samples from four different islands are analyzed (Table). Sixty four diatom taxa were identified from peat deposit McDonald point of Shemya Island. Results of this paleoreconstruction have been published by Neplyukhina et al. (2018a; 2021). In addition, a new diatom - *Pinnularia arkadii* was described from this peat deposit (Neplyukhina et al., 2018b).

Ninety diatom taxa were identified from peat deposit CR-03 of Carlisle Island, the paleoreconstruction

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Fig. The map of Aleutian Islands and position of islands, where samples were collected.

was completed. The results of paleoreconstructions for Shemya and Carlisle Islands reveal the same patterns in history of two Holocene waterbodies. Three hundred nine diatom taxa were identified from modern waterbodies of Unalaska Island (Neplyukhina and Gololobova, 2021). Diatoms of two peat deposits of Unalaska Island and peat deposit of Adak Island are in the process of identification for diatom analysis and further paleoreconstructions.

4. Conclusion

The diatom communities of two Holocene waterbodies are described, their historical change is studied. Modern diatom flora of Unalaska Island is also described. Diatoms communities of three peat deposits are in the process of describing. Two of the five paleoreconstructions have been performed, the performance of the remaining ones will make it possible to build a comprehensive picture of the Holocene climate for this region.

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Conflict of interest

The authors declare no conflict of interest.

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Table. Information about samples and taxa number from different Aleutian Islands.

Island name	Samples localities	Number of samples	Taxa number	Commentary
Shemya Island	McDonald Point peat deposit	76	64	<i>Pinnularia arkadii</i> described
Carlisle Island	CR-03 peat deposit	70	90	
Adak Island	Adak'97 peat deposit	20	> 89	
Unalaska Island	Modern waterbodies	12	309	
	Icy Creek peat deposit	21	> 200	In the process of identification
	Iliuliuk peat deposit	54	> 190	In the process of identification

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The dynamics of vegetation and environmental conditions in the southern Yamal Peninsula during the Holocene inferred from the palynological analysis of lake sediments

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ABSTRACT. Based on the palynological analysis of the bottom sediment column of the arctic lake with the code name 21-Ya-01A of the Erkuta River basin from the southeastern part of the Yamal Peninsula, we received preliminary information on climatic changes, as well as on changes in vegetation character in the area around the water body. According to the results of the palynological analysis, the area around lake 21-Ya-01A was occupied during the Holocene by tree species (dwarf birch, spruce, larch) and characterized by a much warmer climate than today. It has been determined that the lower part of the column from 122 cm to 95 cm formed when dwarf vegetation and light birch-spruce forests covered the territory at that time. The middle part of the column from 95 cm to 15 cm laid under more favorable conditions - the climate was warmer and wetter than in the previous phase. It can be assumed from the spectra from 15 cm to 0 cm of the column that the climate was characterized by even colder temperatures and that the territory turned into a dwarf shrub–yernik tundra.

Keywords: pollen, spores, flora, bottom sediments, climate, north of Western Siberia

1. Introduction

Lake sediments are important environmental archives that document the history of ecosystems, especially of those located at high latitudes (Subetto, 2009). Here we performed a spore-pollen analysis of the sediment core from lake 21-Ya-01A (68°11' N, 68°57' E) in the Erkuta River basin to reconstruct the palaeovegetation dynamics in the southeastern part of the Yamal Peninsula. The region under study has a rigorous climate: low temperatures and high humidity, strong winds, permafrost (Shabanova, 2013). The mean annual temperature is -9°C. The annual precipitation rate is estimated at 295 mm/yr. The frost-free season lasts 68 days. The snow cover becomes stable in September and does not melt away until early June, i.e., for about 247 days. July is the warmest month of the year, with the mean temperature increasing to +5 – +13°C, and February is the coldest, with the mean temperature dropping to -22 – -27°C (Czernyadjeva, 2001). The entire territory lies within the southern subarctic tundra subzone where bushes (alder, willow, dwarf birch thickets called yerniks) are natural and floodplains are occupied by larch and spruce-larch light forests, as well as grass-moss fens, polygonal and palsa bogs. Areas with typical bog plants alternate with

tundra vegetation. Hence, tundra-bog and bog-tundra complexes are common (Yurtsev, 1978; Morozova and Magomedova, 2004). Lake 21-Ya-01A is surrounded by plant communities typical of the shrub-moss tundra and dominated by dwarf birch, willow, cottongrass, cloudberry, horsetail, and mosses.

2. Materials and methods

A 124-cm-long core of bottom sediments was recovered from the central part of lake 21-Ya-01A (68°11.272' N, 68°57.099' E) during the summer expedition in 2021. For palynological analysis, a total of 62 samples taken at 2-cm intervals were used. Prior chemical treatment of the samples was carried out with the help of the Faegri–Iversen method, but without the acetolysis stage (Faegri and Iversen, 1989). Microscopic examinations were made at x400 magnification under a light microscope Axio Imager A2 (Carl Zeiss, Germany). Identification of pollen and spores was performed using special keys (Kupriyanova and Aleshina, 1972; 1978). Each sample was spiked with a tablet of *Lycopodium clavatum* spores (Lund University, Batch 1031) to determine the concentration of pollen grains in the bottom sediments (Stokmarr, 1972). At least 310 palynomorphs per sample were found. Percentages of

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all taxa were calculated from the total pollen sum taken as 100% (spores and non-pollen palynomorphs were not considered). A spore-pollen diagram was created with the Tilia/TiliaGraph software (Grimm, 2004). The boundaries of pollen zones were defined with the CONISS software (Grimm, 1987).

3. Results and discussion

The bottom sediments of lake 21-Ya-01A are made by loose aleuritic silt of gray and light brown colors. The palynological analysis revealed 37 palynomorphs (9 tree, 23 grass, and 5 spore palynomorphs).

All the fossil spectra obtained were characterized by high percentages of arboreal pollen, such as *Betula sect. Nanae*, *Betula sect. Albae*, and *Alnus spp.* Among the non-boreal taxa, Cyperaceae pollen prevailed. Spores mostly belonged to *Sphagnum spp.*

Three palynozones were distinguished in the spore-pollen diagram. The spectra of palynozone I (PZ I, 122–95 cm) are clearly dominated by the pollen of dwarf shrubs: the percentage of *Betula sect. Nanae* and *Alnus spp.* in the bottom sediments is up to 56 and 15%, respectively. *Betula sect. Albae* pollen presented (up to 10%). The pollen record of this zone is also marked by the significant proportion of pine species: *Pinus s/g Haploxylon* (up to 10%), *Picea sp.* (up to 5%); Pinaceae and *Picea s/g Diploxylon* pollen is registered. Non-boreal pollen is largely ascribed to Cyperaceae (up to 17%), Poaceae (up to 11%), and Ericaceae. The content of *Sphagnum spp.* spores reaches 15% (maximum); Lycopodiaceae and Polypodiophyta spores are present as well. The pollen density increases toward the end of the zone (3.8×10^4 grains/g). The analysis of the pollen spectra shows that dwarf vegetation and light birch-spruce forests covered the territory at that time.

Palynozone II (PZ II, 95–15 cm) has higher pollen levels. The maximum pollen density (14×10^4 grains/g) is observed at the depth of 82–78 cm. The pollen spectra indicate an increase in the concentration of motley grass pollen and the high levels of pollen grains identified as *Alnus spp.* (30%), Cyperaceae (15%), and Ericaceae (up to 10%). *Larix sp.* and *Picea sp.* pollen was noticed. The vegetation cover of this period was still dominated by dwarf shrubs, birch forests with spruce and larch trees were present. The spectra suggest that the climate was warmer and wetter than in the previous phase.

In palynozone III (PZ III, 15–0 cm), dwarf birch pollen becomes the most widespread (up to 60%). *Betula sect. Albae* pollen was not detected in the spectra. The content of Cyperaceae pollen is quite high. The pollen density is $5\text{--}11 \times 10^4$ grains/g. It can be assumed from the spectra that the climate was characterized by even colder temperatures and that the territory turned into a dwarf shrub–yernik tundra.

4. Conclusions

According to the results of the palynological analysis discussed above, the area around lake 21-Ya-01A was occupied during the Holocene by tree species

(dwarf birch, spruce, larch) and characterized by a much warmer climate than today. The pollen grains of pine and cedar were probably alien to this region and might have got there from other locations (Vasil'chuk et al., 1983; Panova et al., 2008).

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Subfossil records of Cladocera from the tundra Lake Yambeto in the Yamal Peninsula

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ABSTRACT. We performed a paleoecological study of a 124-cm-long sediment core from Lake Yambeto (southern part of the Yamal Peninsula, Yamalo-Nenets Autonomous Okrug, Russia), which consists of a series of lake basins varying in depth (up to 6.9 m) and merged with each other. The species composition of subfossil cladocerans was analyzed: a total of 26 taxa from 5 families were identified; of them, 73% belonged the family Chydoridae, thus ranking it as the most diverse. The cladoceran assemblage was dominated by Holarctic and Palearctic species, with *Bosmina (Eubosmina) longispina*, *Bosmina longirostris*, and *Chydorus cf. sphaericus* as the most abundant. The mean saprobity index (1.52) characterized the lake as β -mesosaprobic.

Keywords: paleoecology, Yamal Peninsula, subfossil Cladocera

1. Introduction

Layer-by-layer sedimentological analysis reveals a lot about the history of lake biocenoses and their inhabitants (Smirnov, 2010). Paleoclimate reconstructions are often based on pollen and diatoms, both valuable bioindicators of environmental change (Nigamatzyanova et al., 2020; Valieva et al., 2020). Another important source of data on past climate trends is subfossil cladoceran remains that accumulate abundantly in lake sediments: their chitinous structures (headshields, carapaces, postabdomens, postabdominal claws, etc.) are typically well-preserved and thus can be relatively easily identified to the species level (Frolova and Ibragimova, 2015; Nigmatullin et al., 2021). Notably, cladocerans are very responsive to environmental changes. In this light, a proper understanding of the natural climate variability during the past and its impact on fresh-water ecosystems is essential for predicting both current and future climate transformations (Nevalainen et al., 2011). This article discusses the results of our study of Lake Yambeto (southern part of the Yamal Peninsula) aimed to model its past environmental conditions and to estimate the species richness of its cladoceran assemblages.

2. Materials and methods

A core of bottom sediments for subsequent paleontological study was sampled at a depth of 6 m from Lake Yambeto (68°11'74.7"N 068°58'42.8"). The

obtained core was cut into 1 cm thick segments. Prior treatment of the segments was carried out using the standard method (Korhola and Rautio, 2001). The dry segments (0.5–1.0 g) were heated in 10% KOH at 75°C for 30 min, rinsed through a 50 μ m sieve, and examined under an AxioLab A1 light microscope at 100–400 $\times$ magnification. Cladocerans were identified using special keys for subfossil remains (Szeroczyńska and Sarmaja-Korjonen, 2007) and modern species (Kotov et al., 2010; Korovchinskii et al., 2021).

3. Results and discussion

A total of 26 cladoceran taxa from 15 genera and 5 families (Chydoridae – 73%, Bosminidae – 8%, Daphniidae – 12%, Euryceridae – 4%, and Sididae – 4%) were identified in the lake zootheranocenoses. The concentration of subfossil cladoceran remains per 1 g of the dry segment weight varied from 87 to 390 ind./g (249 ind./g on average). *B. (Eubosmina) longispina* was the dominant species (2804 ind., 40.1%). *Ch. cf. sphaericus* (1978 ind., 28.3%) and *B. longirostris* (1317 ind., 18.8 %) were the secondary species. *Graptoleberis testudinaria*, *Pleuroxus uncinatus*, and *Eurycercus* sp., all indicating the overgrowing of some areas in the lake, were also recorded. Pelagic species were the most abundant, but littoral species, mostly from the family Chydoridae, were characterized by a higher taxonomic diversity. A large proportion of taxa included species confined to the Palearctic and Holarctic zones. The Pantle-Buck saprobity index varied from 1.40 to 1.64

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(1.52 ± 0.96 on average), which is characteristic of β -mesosaprobic conditions.

4. Conclusions

The sediment core from Lake Yambeto contained 26 subfossil cladoceran taxa. *B. (E.) longispina*, a pelagic species, prevailed. *B. longirostris*, a small-sized species, and *Ch. cf. sphaericus*, a littoral dweller, were less abundant. The data obtained show that the species diversity of the lake is determined by littoral taxa and species native to northern regions. The values of the saprobity index suggest that the lake is β -mesosaprobic.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Sedimentological records of catastrophic mass movements in the lake bottom-sediments of north-western Kola Peninsula and possible scenarios to explain the seismogenic trigger

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ABSTRACT. In this present article, we describe disturbances in the sedimentary records of lakes on the western flank of Lake Imandra (NE Fennoscandia, Kola Peninsula). The research framework comprises sedimentological and textural criteria for a visual description of sedimentary structures, borehole drilling data, chronological (radiocarbon dating) data, and ground-penetrating radar (GPR) data. Synchronicity specific features and fast spontaneous sediment accumulation in lakes, as well as traces of strong prehistoric and historical earthquakes and geomorphic setting in the studied area suggest that the observed mass movements in lake sediments are potentially generated by earthquake shaking.

Keywords: isolated reservoirs, paleolimnology, paleogeography, earthquake, Holocene, Kola region, Russia

1. Introduction

Lacustrine sediments are a great source of information concerning different environmental changes including the Holocene tectonic settings. Landslides, homogenites, turbidites, and mass movements that occur in lake bottom sediments may form in the result of climate changes, lake or sea level variations, slope overloading and etc. It is also not uncommon that they are generated during the earthquake shaking. These processes can be revealed not only in seismically active areas and subduction zones but also in regions of moderate or low seismicity (Chapron et al., 1999; Ojala et al., 2019). Disturbances in the primary stratigraphy of lake bottom sediments caused by extreme events (earthquakes, tsunami) of the Kola Peninsula were first discovered a few years ago (Nikolaeva et al., 2017; Tolstobrov et al., 2018). These disturbances were discovered in one water basin for the most occasions and in two water basins for a less common part of them. Therefore, the identification of disturbances was rather complicated as well as the bringing of disturbances into undeniable correlation with a seismic event.

In this article we provide new results of the studies sedimentary records of four lakes on the western flank of Lake Imandra (NE Fennoscandia, Kola Peninsula). In addition to the previous research (Nikolaeva et al., 2017) we studied new cores from 4 lakes where we

found traces of catastrophic processes. The studies have focused on sedimentological characteristics of the sediments, geochronological data (^{14}C), paleogeographic reconstructions, and GPR surveys.

2. Materials and methods

The lake bottom sediments were studied using the Russian peat corer. Holes were drilled to parent rocks or moraine. Each core sample was of 1 m length and 54 mm in diameter, the samples were picked with an overlap of 5–10 cm. Visually recognizable core attributes (color, texture, inclusions and mechanical composition) were studied to compose a lithological description of core and mark its stratum boundaries. The lake elevation was determined using topographical maps of 1:25 000 scale. Radiocarbon dating of ten bulk organic sediment samples was processed in the Radiocarbon Laboratory of St. Petersburg State University using the conventional approach. Measurements and calculations of radiocarbon dates were provided according to the techniques described by Arslanov et al. (1993).

3. Results and discussion

Bottom sedimentary sequences from small lake basins at the altitudes of 128.7 to 136.4 m a.s.l. in the coastal area of Lake Babinskaja Imandra consist

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of the lower minerogenic unit (basal part) and the upper organogenic one. The basal part is represented by intercalation of sands and silt. The upper unit is represented by gyttja. Sand and silt deposits were formed in a periglacial environment, from the end of the Younger Dryas to the beginning of the Preboreal, under glacial degradation conditions. Gytja are deposited in the Holocene.

A typical feature of the sediments is the occurrence of brecciated horizon (BL layers) in the gyttja unit. It consists of a mixture of different-shape and different-size pieces and fragments of black and brown ("variously colored") gyttja, silt, peat, sand, plant remains and wood fragments (4–5 cm) enclosed in sapropel matrix. The occurrence of brecciated horizon in the sections implies catastrophic changes in sediment deposition at an early period of quiescent sedimentation.

Radiocarbon dates obtained from the BL layers correspond to the Atlantic Period of the Holocene. A gyttja sample from non-damaged layer underlying the BL in Lake 1 (133.4 m a.s.l.) was dated 7350 ± 270 cal. yr BP, and a wood fragment from the upper part of the BL was dated 6450 ± 340 cal. yr BP. The age of the BL formation in Lake 4 (128.7 m a.s.l.) is ranged $6600 \pm 150 - 6080 \pm 160$ cal. yr BP. The radiocarbon dates of lakes 1 and 4 are close which indicates the synchronicity of the BL formation, and the updated age of the event is determined approximately as 6400–6100 cal. yr BP.

Georadar sensing of the Lake 1 also showed sediment disturbance and dislocation. The 1.3–1.7 m vertical displacements of layers along the top of the sand and silt unit, as well as sediment-slide areas in gyttja, are clearly defined on the obtained radarograms (Rodionov et al., 2018).

Synchronicity specific features and fast spontaneous sediment accumulation in lakes, as well as traces of strong past earthquakes and geomorphic setting in the studied area suggest that the observed deformations in lake sediments are potentially generated during earthquake shaking.

The studied lakes with BL layers are spatially distributed in a special way, i.e., they are located along the esker of the north-westward trending. We may suggest two conceptual models.

Model I. The formation of BL layers in the bottom sediments of the lakes could be associated with the catastrophic water breakthrough of the Lake 2 across the esker ridge. In accordance with the paleogeographical reconstructions (Korsakova et al., 2020) we may assume that Lake 2 occupied a bigger area ca. 6000–6500 years ago compare to the present. The seismic shock caused the breaching of esker that bounded the lake from the east and discharging of water from the lake. The lake sediments were carried with water currents downward the slope eroding the local environment. These "mud streams" moved from north to south along a narrow zone between the two esker ridges and deposited on the already accumulated non-damaged gyttja in the basins of lakes 1, 3, and 4. The elevation difference could be

about 4–5 m judging by the altitudes of the esker and the lake itself and also by possible erosion.

Model II. Synchronous landslides. Off-fault coseismic deformation structures in lacustrine sediments comprise mass movements and small-scale landslides. Sub-aqueous mass failure takes place at the lake sides and can involve different processes of sliding, slumping and flowing of near-shore lake sediments.

The earthquake, which presumably was a trigger for the formation of the landslides, was generated by the activation of ancient fault zone of the NE strike or by the activation of sublatitudinal faults bounded of Babinskaya Imandra depression.

Anyway, whatever the model might be, we have clearly established the sudden and instantaneous character of sediment formation indicating the catastrophic event most probably triggered by an earthquake. The simultaneous formation of anomalous sediments in several lakes and their lithology along with the Holocene tectonic activity of the Lake Imandra depression all substantiate the idea of a seismic trigger.

4. Conclusions

The studies allow us to enlarge our knowledge on seismically induced events and processes in the lake bottom sediments. The observations from the present study extend the paleoseismic catalogue by identifying new evidence of Mid-Holocene earthquake in northeastern Fennoscandia. They also provide basis for adjustment of seismic hazard assessments of the platforms that were long considered nonseismic and contribute to the identification of release mechanisms of a seismic shock.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Composition of the terrigenous component in the bottom sediments of the Lake Onego different areas

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ABSTRACT. This article touches upon the terrigenous component of the Lake Onego bottom sediments. The terrigenous component represented by quartz, feldspar, and muscovite is spread throughout the lake's water area and corresponds to the composition of the parent rocks of the lake's catchment area. Dark-colored minerals (amphiboles, pyroxene, epidote, etc.) are unevenly distributed, and reflect local sources of terrigenous material in some bays and areas of the lake (Petrozavodsk Bay, Central Onego, South Onego). In the areas of Big and Small Onego, Povenetsky and Zaonezhsky Bays, local sources of terrigenous material are not found in the upper horizons of the bottom sediments.

Keywords: Lake Onego, bottom sediments, terrigenous component, dark-colored minerals, accessory minerals

1. Introduction

Lake Onego is the second-largest water body in Europe (Onezhskoe ozero..., 2010), in terms of both size (9720 km²), volume of water mass (291.7 km³) and the catchment area 62.8·10³ km² (Onezhskaya paleoproterozojskaya struktura..., 2011) and has a complex morphology. The lake is divided into large areas, for example, Kondopoga, Great, Unitsky, Lizhensky, Povenetsky and Zaonezhsky Bays are in the north, Petrozavodsk Bay is in the west, the areas of Big, Small and Central Onego are in the center of the lake. The South Onego is in the southern part of the lake. The Lake Onego depression is located in the northwest part of the European Russia in the contact zone of the Baltic crystalline shield (early Precambrian formations composed of 80% rocks of the tonalite–trondyemite–granodiorite (TTG) series) and the Russian Plate (the Vendian-Paleozoic platform cover) (Onezhskaya paleoproterozojskaya struktura..., 2011). Quaternary deposits are represented by moraines of cover and mountain glaciers, glacial-lake and fluvio-glacial sediments.

The lake receives a variety of material: solid phase of river runoff, atmospheric aerosols, coastal abrasion material, anthropogenic substance, and biogenic component.

The work aimed to characterize the mineral composition of the terrigenous component in various parts of Lake Onego.

2. Materials and methods

The sample morphology, phase, and elemental composition were determined with a scanning electron microscope (SEM) Mira 3 Tescan (Tescan, Brno-Kohoutovice, Czech Republic). The current modification of the equipment used a Si(Li) energetic detector (Oxford, Oxford Instruments, Abingdon, UK). The method enabled to carry out a quantitative chemical analysis on micro volumes. The INCA Energy 300 program (Labspec 5) was used for a quantitative chemical analysis with reference standards. All microphotographs presented in this work were taken using the SEM Mira 3 Tescan. X-ray diffractometry (XRD) was applied to determine a sample mineral composition (ARLX'TRA, Thermo Fisher Scientific (Ecublens) SARL, Waltham, MA, USA) (emission CuKα).

Analytical work was done at the Analytical Center for Multi-Elemental and Isotope Research SB RAS, Novosibirsk.

3. Results and discussion

The geochemistry and mineralogy of the Lake Onego bottom sediments were previously considered in several publications of the authors of this work (Strakhovenko et al., 2018; 2020). However, dark-colored and accessory minerals were not detailed for each part of the lake. Analysis by X-ray diffractometry and scanning electron microscopy shows that quartz,

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feldspar and muscovite predominate among the terrigenous minerals in all samples of bottom sediments (alkaline and medium plagioclase, and to a lesser extent potassium feldspar) regardless of the part of Lake Onego (Fig.). It is caused by the wide distribution from the northwestern through the northern to the northeastern part of the lake watershed of the early Precambrian formations of the TTG series, in which quartz and feldspar prevail.

The set of dark-colored and accessory minerals in the bottom sediments in general also corresponds to the composition in the early Precambrian formations of the TTG series and multiple intrusions of basic, medium and acidic composition (gabbro, diorites, granodiorites, granites, etc.). Dark-colored minerals are biotite, pyroxenes (mainly diopside) and amphiboles (most often hornblende), epidote, muscovite. In smaller quantities, there are accessory minerals: rutile, ilmenite, magnetite, titanite, zircon, monazite and hematite (Fig.). Dark-colored and some accessory minerals are unevenly distributed across the lake area.

The grain size of the terrigenous fraction in the bottom sediments varies from 1 to ~50 μm , regardless of the part of Lake Onego (Fig.).

Some dark-colored and accessory minerals are found only in certain bays and areas of Lake Onego, for example, aegirine and chromite are found only in Central Onego. This may be due to the outcrops of the Middle Proterozoic ultramafic and basalt rocks in the catchment area of the river Vodla flowing into Lake Onego in the area of Central Onego. Barite occurs in Central Onego and Petrozavodsk Bay, which may be associated with effusive rock outcrops in the Petrozavodsk Bay area. A specific feature of South Onego is the presence of kaolinite and phlogopite in the bottom sediments. The presence of kaolinite correlates with the weathering of feldspar rocks, which prevail in the lake's catchment and phlogopite can come with aeolian material. This distribution of the terrigenous dark-colored minerals relates with the peculiarities

of the composition of rocks of the catchment area in general and each bay, and the lake area in particular. There is a large number of fragments and grains of epidote, hornblende, actinolite, and diopside in the Lake Onego bottom sediments. However, there are almost no pyroxenes and hornblende in the Big and Small Onego areas.

If for the above-mentioned areas of the lake, the rock's composition of the catchment area reflects the composition of bottom sediments, then the terrigenous component of carbonate and shungite composition is not traced in the bottom sediments of the northwestern and northeastern bays of Lake Onego, although there are outcrops of the corresponding rocks on the shores.

4. Conclusions

Based on the Lake Onego location and morphology, the composition of the terrigenous component of the bottom sediments reflects the composition of the rocks of its catchment area in general and each bay in particular. The main part of the terrigenous component is quartz and feldspar for the entire water area of Lake Onego. Accessory and dark-colored minerals are unevenly distributed.

The main distinctive features of the content of dark-colored minerals in the bottom sediments are observed by (a) the content of pyroxenes: aegirine is found only in Central Onego, diopside is found in almost all bays, and there is a complete absence of pyroxenes in the Big and Small Onego areas; (b) the presence of kaolinite and phlogopite in South Onego; (c) the absence of shungite and carbonate material in the north-western and north-eastern bays of Lake Onego.

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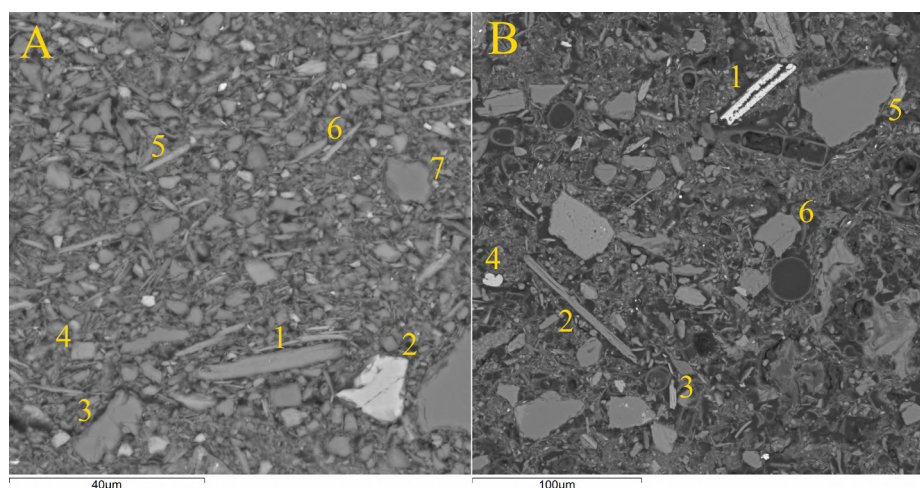


Fig. Terrigenous component of the bottom sediments of (A) Zaonezhsky Bay (northern part of the lake): 1-muscovite, 2 – titanite, 3 – oligoclase, 4 – potassium feldspar, 5 – chloritoid, 6 – chlorite, 7 – quartz; (B) South Onego (southern part of the lake): 1 – ilmenite, 2 – muscovite, 3 – pyroxene, 4 – rutile, 5 – quartz, 6 – potassium feldspar.

Conflict of interest

The authors declare no conflict of interest.

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The early Holocene paleogeography of Yurumkuveem river basin (Central Chukotka)

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ABSTRACT. Results of radiocarbon dating and spore-pollen analysis of lacustrine sediments in the Nyrki section from the Yurumkuveem river basin (Central Chukotka) show the wider distribution of floodplain forests and the warmer climate in this time in the region in the early Holocene than in the present time. The occurrence of larch (*Larix*) in the vicinity of Nyrki lake in the early Holocene is also discussed. Our data suggest that the larch range was expanded to the Yurumkuveem river valley and its inflows during the early Holocene, but this tree disappeared from there in the late Holocene.

Keywords: Holocene, Chukotka, spore-and-pollen analyses, Quaternary deposits, paleogeography

1. Introduction

The Late Quaternary history the vegetation and climate dynamics of Chukotka as well as the chronology of environmental changes in this region are still poorly known. Many areas of the Chukotka Peninsula have never been covered by palaeogeographical studies. The basin of Kalaravaam-Maliy Pykarvaam-Bolshoi Pykarvaam-Yurumkuveem is one of underexplored regions of Central Chukotka situated on the eastern margin of Anadyr Highlands. The present study aims to reconstruct the history of climate and vegetation of this region during the late Quaternary.

The river system of Kalaravaam-Maliy Pykarvaam-Bolshoi Pykarvaam-Yurumkuveem drains the southern side of the continental divide between Arctic and Pacific Oceans. Although this territory belongs to the subzone of southern tundra (Jurtsev et al., 2010), the poplar-chosenia forests are widespread along the Yurumkuveem floodplain downstream of the mouth of the Bolshoi Pykarvaam River (authors' observations). In general, the area is characterized by poor exposure of the Quaternary deposits, which mainly appear as terraces up to 50 m high showing the variation of lithological composition from sands to boulders. These bodies have been described by S. Obruchev (1938) who interpreted those as moraine terraces.

2. Materials and methods

The materials for this study have been collected during the field trip in 2019. Along our route of about 150 km long, only a few suitable exposures have been found. One of these exposures is situated at the Nyrki lake at the confluence of the Kalaravaam and Maliy Pykarvaam rivers (N 67.856366; E 173.9775). This lake situated between the moraine ridge on the western side, partly cutted by the river, and the fluvio-glacial terrace on the eastern side. Such geomorphological position suggests glacial origin of the lake.

The profile of sediments has been examined at the cliff on the southern shore of the lake. The height of cliff near the exposure was about 4.5 m above the water level, the section thickness was 3.7 meters. The following sediments of lacustrine and eolian genesis found in this section starting from the top: 0-0.1 m – modern soil; 0.1-0.4 m – medium-grained gray-brown sand with roots; 0.45-0.50 m – buried soil of dark brown color with crashed deer bones and fragments of the ceramics; 0.5-1.25 m – medium-grained light brown sand with lenses of coarse-grained sand and rare organic detritus; 1.25-1.55 m – cross-laminated gray sand with layers of coarse-grained sand, contains small amount of organic detritus; 1.55-3.05 m – medium-grained sand of gray color with organic layers (leaves,

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wood fragments, sticks) horizontally laminated; 3.05-3.45 m coarse-grained unlaminated sand; 3.45-3.55 m - gray aleurite with horizontal lamination, contains organic material.

The samples of wood and peat for radiocarbon dating were collected from the layer with the highest organic content of organics (interval 1.55-3.05 m). We also performed radiocarbon dating for a trunk of *Populus* or *Chosenia* and for a fragment of tree bark, which were collected on the beach near the site.

The samples for pollen analysis were collected from the bed with the highest organic content. These samples were taken on 10 cm intervals, and then were processed with the standard hydrofluoric acid method (Berglund and Ralska-Jasiewiczowa, 1986). Pollen concentration was estimated using Stockmarr's (1971) method. Six taxa of trees and shrubs, 20 herbaceous taxa, two taxa of aquatic plants and seven spore taxa have been identified. Spore and pollen diagram was prepared using C2 software kit.

3. Results

The results of dating of wood and peat, sampled *in situ*, showed that the layer with the highest content of organic matter (interval 1.55-3.05 m) was formed approximately between 8 and 4.3 ^{14}C ka yr BP. Age of both wood samples, collected on the beach was around 8 ^{14}C ka yr BP.

Generally, spore-pollen spectra do not show significant changes of vegetation during the period of deposit formation. The pollen of trees and shrubs dominate in the most samples. Variations in the content of individual taxa make it possible to divide the section into 3 palynozones (Fig.).

Palynozone NL-1 (310 - 235 cm) shows the predominance of the pollen of trees and shrub, especially of *Betula* (up to 30%), *Alnus fruticosa* (about 20%) as well as *Salix* and *Larix*. The pollen of Cyperaceae and Poaceae are dominated among herbaceous taxa, and

the pollen of Rosaceae and Ericaceae also occur.

Palynozone NL-2 (235 - 205 cm) is characterized by a slight decrease in the incidence of trees and shrub pollen with higher proportion of herbaceous taxa (mainly Cyperaceae).

Palynozone NL-3 (205 - 170 cm) shows a new shift to the predominance of most aforementioned trees and shrubs, but with the lack of the *Larix* pollen.

In general, the results of the pollen analysis show that the climate before and around 7.9 ^{14}C ka yr BP was slightly warmer than the present, and its slow cooling started since about 4.3 ^{14}C ka yr BP.

4. Discussion and conclusions

Peatbogs and other organic-rich sediments of the Early Holocene age are well known in the Northeast Asia (Lozhkin et al., 2011). A small peatbog with of about 0.5 m thick was discovered by us in the thermokarst depression in the Kalaravaam river valley (N 67.9271; E 173.7217). Radiocarbon dating of a peat sample from this bog showed its Early Holocene age.

According to our data, the poplar-chosenia forests in the early Holocene were distributed at least at the lower reaches of the Maly Pykarvaam river (today they begin to grow about 50 km to the south). Apart from those, the larch populations occurred then around the Nyrki lake. Previously, the larch macroremains have been reported from a peatbog and a permafrost core near the Elgygytgyn lake, in 90 km E from the Nyrki lake. The age of this peatbog was determined as 9250 ± 90 ^{14}C yr BP (MAG-1477) (Shilo et al., 2008) whereas the AMS dating of the larch seeds from the permafrost core showed their age of 9640 ± 60 ^{14}C yr BP (Poz-42874) (Andreev et al., 2012). Our data suggest that the larch range was expanded to the Yurumkuvem river valley and its inflows during the early Holocene, but this tree disappeared from this region as well as from the Elgygytgyn area in the late Holocene.

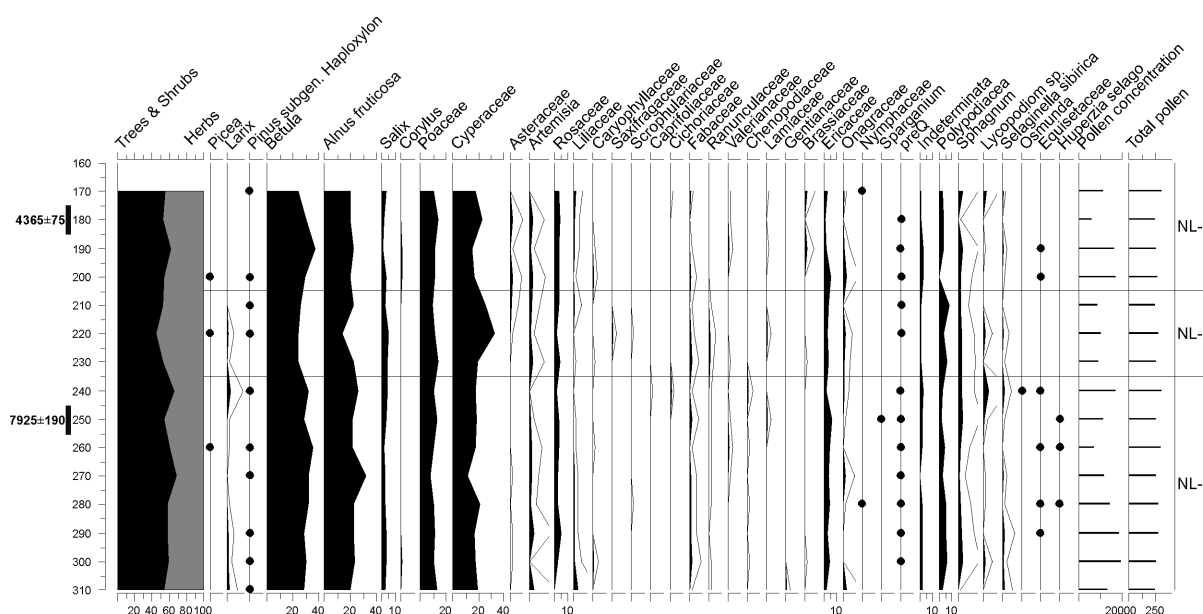


Fig. Spore-and-pollen diagram of the Nyrki lake section.

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Conflict of interest

The authors declare no conflict of interest.

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The Lake Onego watershed: morphology of lakes and classification of the bottom sediments



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ABSTRACT. The data on the lake morphometry and sediment lithostratigraphy of the Lake Onego watershed were collected. The classification of lakes was carried out according to the genetic features of relief. Four types of the lakes have been identified for the catchment area. The structural features of lake basins and bottom sediments were determined for each type of lakes.

Keywords: Lake Onego, lake basins, morphometry, sediments, lithostratigraphy

1. Introduction

Lake Onego (61°42' N, 35°25' E; 33 m a.s.l.) is the second largest freshwater lake after Lake Ladoga located in Europe. The lake has a surface area of 10,000 km² and a catchment area of 53,000 km² (Fig.). The watershed has a well-developed hydrographic network including more than 6500 rivers and 9500 lakes. It has a total lake-surface area of 3500 km² and a lake-surface area density of 6.5%. Waterbodies differ in a variety of limnological characteristics including origin, morphology and sedimentation patterns, etc.

Structure of lake basins and bottom sediments relates to the local geologic and geomorphologic features and history. The catchment area and lake depression are located in the northwest of the East European Platform on the border of the crystalline shield and the sedimentary plate (Fig.). During the Last Glacial Period, they were in the marginal flank of the glacier. The Onego Ice Lake (OIL) was formed in the lake depression in the Late Glacial. The proglacial lake extended beyond the present watershed on the maximum stage of its development (Subetto et al., 2019; Zobkov et al., 2019).

2. Materials and methods

The waterbodies of the Lake Onego catchment area are divided into three groups (Molchanov, 1946): (1) lakes located in cracks and faults of hard-rock; (2) lakes located in depressions of sandy-clayey glacial deposits; (3) lakes located in the area of limestone and covered with sandy-clayey deposits. The first group correlates with tectonic lakes and is located within

the boundaries of the crystalline shield. The second group corresponds to glacial lakes and is placed within the entire watershed. The third group correlates with karst lakes and is spread within the sedimentary plate. However, the complexity and ambiguity of the origin of basins determines the presence of a larger number of genetic types and subtypes. The diversity of the morphometric characteristics and sedimentation features reflects it (Potakhin et al., 2019).

The stratigraphy of Quaternary deposits of the Lake Onego depression is as follows (Saarnisto and Saarinen, 2001; Hang et al., 2019; Subetto et al., 2020; Belyaev et al., 2021). The upper part is composed of lacustrine deposits (homogenized silty-clay gyttja). The middle part contains the limno-glacial deposits (varved clays). The lower part consists of glaciofluvial (sands and pebbles) and glacial (boulder loams) deposition. The organic gyttja is integral for the upper layers of bottom sediments in small lakes. Varved clays are distributed within the territory flooded by the waters of OIL in the Late Pleistocene (Fig.).

We collected the data on morphometric characteristics of 320 lakes and lithostratigraphy of 83 lakes. The literary, cadastral and archival sources, as well as expeditionary materials were used. The classification of lakes was carried out according to the genetic features of watershed relief. This approach was applied to Swedish lakes (Håkanson and Karlsson, 1984) located in similar environmental conditions of Fennoscandia. The ranges of variation and average values of morphometric characteristics were calculated, and structural features of bottom sediments were identified for each type of lakes.

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3. Results and discussion

Four types of lakes have been identified for the Lake Onego catchment area.

(I) Lakes of lacustrine plains (Vodlinskaya, Prionezhskaya and Shuiskaya, etc.) are characterized by a lower altitude, rounded shape and shallow depths. Relic lakes of the proglacial waterbody, and lagoon lakes represent them. The lower part of the bottom sediments is composed of varved clays (beginning of sedimentation about 16-15 cal ka BP). Silts (beginning of organogenic sedimentation about 10 cal ka BP) overlie the clays (Subetto, 2009).

(II) Lakes of till plains are characterized by a simple form and shallow depths. They are represented by glacial deposit-dammed basins (moraine-dammed lakes). The lower part of bottom sediments contains clays, loams and sandy loams overlain by silts (beginning of organogenic sedimentation about 9.5-10 cal ka BP).

(III) Lakes of marginal formations' uplands (Veshkelskaya, Vokhtozerskaya, Vodlozerskaya, etc.) are characterized by a higher altitude, small sizes and various depths. They are represented by glacial basins (moraine-dammed lakes, glaciokarst, etc.), and karst lakes in the southern part of the catchment area. The lower part of the bottom sediments is composed of clays, loams and sandy loams overlain by silts (beginning of organogenic sedimentation about 9.5-10.5 cal ka BP) (Subetto, 2009).

(IV) Lakes of denudation and tectonic relief are characterized by large size and elongated shape, high depths and cone-shaped basins. They are formed by tectonic lakes (depressions of synclinal and anticlinal folds, fault-line depressions, etc.). Two altitudinal levels of distribution of these lakes are distinguished: 35-75 m (lakes of the Zaonezhsky Peninsula) and 115-185 m (lakes of the West Karelian Upland). The first subtype marks the similarity in the structure of bottom sediments with type I, while the second subtype is similar to type II.

The organic gyttja features the recent lacustrine deposits of small lakes of the Lake Onego catchment. Most of the catchment area is located within the Fennoscandian Crystalline Shield (Fig.) and belongs to the region of Fe-Si-humus sedimentation, the Fe-humus sedimentation sub-region. The southern part is located within the Russian Sedimentary Plate and belongs to the region of organic sedimentation (Rossolimo, 1964). However, the studied lakes differ in the type of sedimentation. For example, the Fe-Si-humus type of sedimentation is predominant for small lakes of the Vokhtozero Upland and (III) and Fe-humus-Si type for large lakes. The lakes of the Zaonezhsky Peninsula (I, II and IV) are expressed by a mixed type of sedimentation (Fe-Si-humus, Fe-humus-Si or humus-Fe-Si in accordance with the increasing mass fraction of the component in the sediment composition), but small lakes may have a monotype (humus, where organic matter makes up more than 80% of the sediment composition, or diatom sediments, where biogenic Si makes up more than 30% of the sediment composition) (Belkina and Kulik,

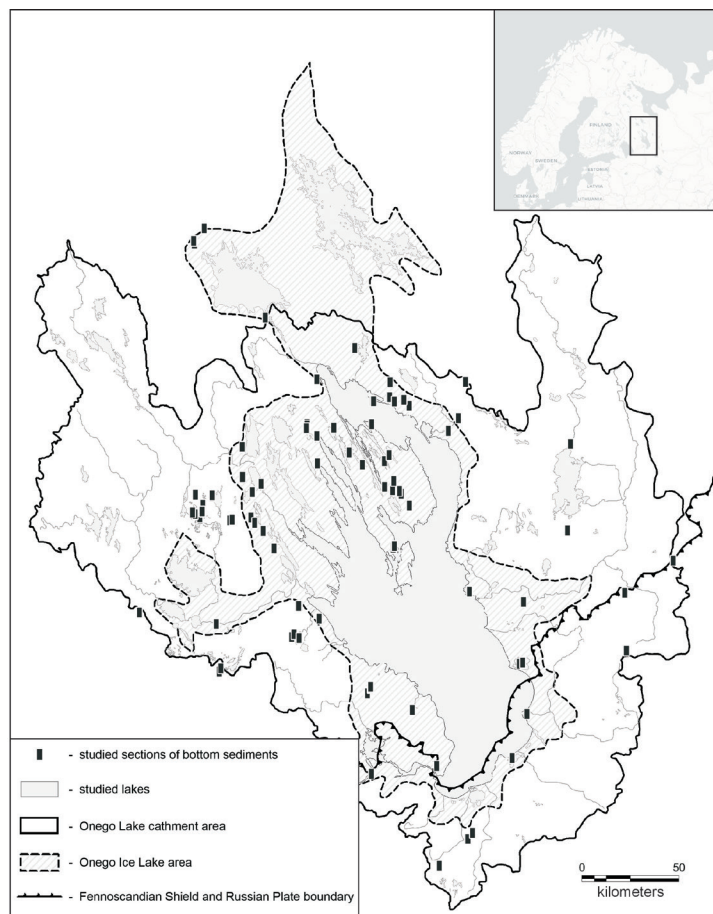


Fig. Lake Onego and its watershed.

2019). Differences in sedimentation are determined by landscape features of watersheds (composition of rocks, relief, soils, vegetation, economic activity, etc.) and features of lakes (basin morphology, hydrological regime, chemical composition of water, biological characteristics).

4. Conclusions

For the Lake Onego catchment area, the four types of lakes have been identified, depending on the main types of relief: (I) lakes of lacustrine plains; (II) lakes of till plains; (III) lakes of marginal formations' uplands; (IV) lakes of denudation and tectonic relief. The structural features of lake basins and bottom sediments were identified for each type of lakes. We discover the morphogenetic features of lake basins and the landscape conditions of watersheds are local factors that affect the spatiotemporal transformation of lakes in the course of their development since the last deglaciation.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Gran-size and chironomid analyses of the upper sediment core of Lake Usvyatskoye (Pskov region, Russia)

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ABSTRACT. Grain size and chironomid analyses of the upper core of the Usvyatskoye Lake (Pskov area) were carried out. The estimated age of the core covers the last 2000 years. Preliminary results of grain-size analysis identified four facies in the studied core. Analysis of chironomid taxonomic composition showed a change in dominant taxa, that is correlated with changes in grain size.

Keywords: Paleolimnology, lake bottom sediments, grain-size analysis, chironomid analysis, The trade route from the Varangians to the Greeks, Lake Usvyatskoye, North-Western Russia.

1. Introduction

The main aim of our research is to perform paleoclimatic and paleoenvironmental reconstruction of the watershed area of the Western Dvina, Lovat and Dnieper rivers. Assumedly “The trade route from the Varangians to the Greeks” passed here in the 11-12th century (Grekov et al., 2022). Paleolimnological investigation of this area may help to understand the natural and human history of the territory during this period.

2. Materials and methods

The object of our research is the Usvyatskoye Lake (55.72N, 30.79 E), which belongs to the basin of the Western Dvina River, Pskov region. The lake is located on a large watershed section of “The trade route from the Varangians to the Greeks”, in the Usvyacha river's course.

For a short core from Lake Usvyatskoe (estimated age 2000 years), grain-size and chironomid analyses were carried out.

The results of grain-size analysis are used to determine the nature of changes in the granulometric composition of sediments, to establish the nature of hydrological and water level regimes of the lake in the past (Karevskaya and Panina, 2012). Organic elements were removed from the samples using a 37% hydrogen peroxide solution and distilled water in a 1:1 ratio. The grain-size analysis of the samples was carried out in the Laboratory of Paleolimnology of the Herzen University using the laser particle analyser LASKA. During sample preparation, the sediment core was divided with 1 cm resolution.

Sample treatment for the chironomid analysis was performed followed standard technique (Brooks et al., 2007). Samples for chironomid analysis were taken from the upper part of the column from 1.20 to 1.85 m. Chironomids were identified with reference to Wiederholm (1983) and Brooks et al. (2007). The biodiversity and evenness of chironomid communities were assessed using Shannon's indices (H) (Shannon and Weaver, 1963) and Pielou's indices (I) (Pielou, 1966)

3. Results and discussion

3.1 Grain-size analysis

The core is dominated by fractions of physical clay – silt (fine and coarse), fine and medium dust, as well as coarse dust belonging to the fraction of physical sand.

Facies boundaries are drawn along the depths at which sharp changes in the size of mineral particles are noted and which separate core gaps of similar particle sizes from each other.

The first (1.16-1.36), third (1.56-1.82) and fourth (1.82-2) facies are characterized by the predominance of physical clay and slightly smaller average particle sizes than in the second facies.

In the second facies (1.36-1.56), an increase in the proportion of coarse dust (10-50 microns), which belongs to the fraction of physical sand, is clearly traced. The maximum content of large particles falls on the sample from a depth of 1.35-1.36 meters. The increase in the size of mineral particles probably indicates an increase in the speed of the Usvyacha River. This peak may be related to the vigorous all agricultural activity

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in the region in the 20th century. This peak may be related to the vigorous all agricultural activity in the region in the 20th century.

3.2 Chironomid analysis

Identified chironomid head capsules belong to 52 taxa. The analysed taxa belong to 3 subfamilies: *Chironominae*, *Orthocladinae*, *Tanypodinae*. According to the results of cluster analysis, three statistically significant zones were identified in the studied column of sediments.

In the lower part of the core (1.70-1.84 m), the Shannon and Piellow index values are low, along with the total number of taxa. This may be due to a certain cooling of the climate during this period. Subsequently, biodiversity and evenness of communities increase. This may indicate warm climatic conditions and high-water levels in the reservoir. There are profundal species of chironomid, which indicates a high-water level. In the range from 1.39 to 1.58 m, the reconstructed conditions of this period are characterized by the appearance of cold-water stenothermal taxa, which may indicate some cooling of the climate. The Shannon and Piellow index values drop to $H \sim 2.3 - 2.5$ and $I \sim 0.37 - 0.55$, respectively. In the upper part of the core (1.39 – 1.20 m), we observe a change in the dominant taxa: in this area, the number of *Pseudochironomus acidophilus* and *Dicortendipes nervosus*-type increases. This indicates some eutrophication of the lake. The occurrence of cold-water stenothermic taxa may indicate some cooling of the climate. The zones described above characterize the studied core as a change in warm and cold climatic conditions in the entire core. Water level fluctuations in the lake are also recorded.

4. Conclusions

The relationship between particle size distribution and chironomid analysis can be clearly seen. The last zone (1.20 - 1.39 m) can be attributed to the last 100-200 years. The predominance of the clay fraction characterizes the slow movement of water in the lake and the increase in its level, which is reflected in the nature of the species living in the lake. Sharp fluctuations in graphs with anomalies can fix active anthropogenic activity in the watershed. For a long time before this, the period of cold natural conditions (1.39-1.56 m) is characterized by the highest values of the sand fraction in the bottom sediments of the reservoir throughout this core. This indicates a more intense runoff of the Usvyacha River and other watercourses flowing through Lake Usvyatskoe. Below this, a warm zone is fixed (1.56-1.72 m) characterized by a large number of the smallest fractions in granulometry and profundal chironomid species, which indicates that the water level at that time was noticeably higher than the current one. Before this period, cold-water conditions are observed again.

This alternation of warm and cold periods with very different natural conditions corresponds to the last

1200 years of history (Arslanov et al., 2020; Nirgi et al., 2021). Based on this assumption, it can be said that the cold long period belongs to the Medieval Little Ice Age, and noticeable warm conditions correspond to the Medieval Climatic Optimum (approximately 900-1350 AD). It was at this time that there were the most full-flowing and hottest conditions in the history of the lake over the past 1200 years.

Preliminary results of grain-size analysis and chironomid analysis of bottom sediments of Lake Usvyatskoye show a clear change in sedimentation processes in horizons 136 – 148 cm (~ 1950-1300 yrs.). These data suggest a change in natural and climatic conditions during the study period.

In order to clarify results and perform quantitative reconstruction, it is planned to supplement with data from pollen and geochemical analysis, as well as radiocarbon dating.

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Conflict of interest

The authors declare that there is no conflict of interest.

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The mechanism of formation and degradation of the Chuya-Kuray ice-dammed lake



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ABSTRACT. The results of the study of the stratigraphic structure, granulometric composition of the sediments of the ridge relief, the heights of shorelines and the water balance of the Chuya-Kuray ice-dammed paleolake (Altai Mountains) are presented. It is established that the ridge relief is an alluvial fan of fluvio-glacial temporary watercourses. The magnitude of floods during the drainage of the paleolake reached 800-2160 m³/s.

Keywords: ice-dammed lake, giant current ripples, Altai Mountains, paleoshoreline

1. Introduction

Among the Neo-Pleistocene ice-dammed paleolakes studied by researchers that existed in North America and Eurasia, the most famous are the Columbia River basin paleolakes – Missoula, Spokane, Bonneville, etc. (O'Connor et al., 2020), Lake Vitim (Margold et al., 2018). As a rule, ice-dammed paleolakes occupied intermountain depressions, within which various lacustrine geomorphological relics were preserved. Such relics include *ancient shoreline*, the cover of *lacustrine sediments*, *dropstones* and fields of *ridge relief* at the bottom of depressions, the origin of which causes debate among researchers. Anomalous high river terraces downstream are indicated more full-flowing conditions in the past. The formation of ice-dammed paleolakes is mainly associated with the growth of mountain-valley and cover glaciers during the Pleistocene glaciations and subsequent damming of draining valleys (O'Connor et al., 2020).

One of the notable examples of Neo-Pleistocene paleolakes is the Chuya-Kuray ice-dammed lake located in the southeastern part of the Altai Mountains. In the course of a long history of studying this territory, researchers have been discussing many aspects of the evolution of the Chuya-Kuray ice-dammed lake. The most discussed issue is the problem of estimating the rate of drainage of the paleolake and the parameters of floods during the destruction of the ice dam. Currently, there are two main views on this issue:

1. according to the researches (Baker et al., 1993), upon reaching the maximum level of filling of the

lakes, the erosion of the ice dam began, lead to catastrophic drainage of a large volume of water within a few days or weeks. Thus, the observed geomorphological relics within the basins and downstream river valleys, by analogy with the territory of the Missoula paleolake, represent a *scabland* – a territory exposed to a catastrophic flood, the accumulative formations of which are composed of *diluvium*. The main argument in favor of this hypothesis, the authors cite the presence of ridge relief fields at the bottom of the depressions – a *giant current ripples*, which is considered an analogue of river dunes at the bottom of river flows (Baker et al., 1993). Based on this interpretation, numerical parameters of megafloods were estimated in further studies (Agatova et al., 2020). According to the latest of them (Bohorquez et al., 2019), water flows were characterized by discharge of up to 10.5 million m³/s and a flow rate of up to 40 m/s, which lasted 33.8 hours.

2. the hypothesis of a catastrophic flood was criticized (Okishev and Borodavko, 2001; Pozdnyakov and Khon, 2001) in a number of other studies. In these researches, the authors point out the essential contradictions of the catastrophic hypothesis to the hydrodynamic laws. These contradictions are connected with the impossibility of simultaneous formation of conjugate landforms in a rapid water flow - channel ridges at the bottom of basins and lacustrine shoreline on the slopes of basins. This contradiction is eliminated if we accept

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an alternative interpretation of the genesis and mechanism of formation of ridge relief. In addition, the very presence of a series of lacustrine shorelines indicates a slower and gradual nature of the drainage of the lake.

Thus, the aim of the study is the systematic interpretation of geomorphological relics in the Chuya and Kuray basins and the revelation of the mechanism of formation and degradation of the paleolake. The key objectives of the study are: to determine the genesis of the ridge relief of the Kuray basin and estimation possible magnitude water flows of tributaries and sources of the paleolake.

2. Materials and methods

To determine the genesis of the ridge relief, transverse and longitudinal profiles, stratigraphic and lithological structure of deposits of morphologically typical ridges were studied using pits and channels. In our work, we focused on the study of the granulometric composition deposits (d) and the calculation of the hydraulic size of debris (ω). The hydraulic size of sediments is the rate of particle fall in standing water. A ratio of hydraulic size to flow rate shows the resistance to erosion and the hydrodynamic environment of transportation of sediments. The hydraulic size of debris was calculated using the equation (Altschul et al., 1977):

$$\omega = \sqrt{\frac{4}{3}g} \cdot \sqrt{\frac{d(\rho_d - \rho_w)}{C_d \rho_w}}, \quad (1)$$

where g is the acceleration of gravity, d is the size of grains (cm), ρ_d is the density of the debris; ρ_w is the density of water; C_d is the coefficient of resistance (for spherical debris – 0.45, for rectangular debris – 2).

Quantitative estimation of the volumes of water released during the drainage of the paleolake is possible by analyzing the distribution of heights of shorelines. It is obvious that the absolute height of the shoreline corresponds to the former level of the water area. Since the formation of one shoreline could only occur during the warm season of the year, equal to 3 months in periglacial conditions, the difference between the height of neighboring shorelines allows us to find the height of the lowering of the water level ΔY (2):

$$\Delta Y = (Y_n - Y_{n-1}), \quad (2)$$

where Y_n is the absolute height of the shoreline and, respectively, the lake level in the initial period, and Y_{n-1} is the absolute height of the shoreline in the subsequent one. To determine the heights of the shorelines, instrumental measurement of the slopes of the basins was carried out, as well as the decoding of satellite images. The volume of water ΔV_n is determined by the equation (2) with a known area $S(Y)$ of the lake's water area at the corresponding level of absolute height and a known height of lowering of the level ΔY :

$$\Delta V = S_n \cdot \Delta Y_n \quad (3)$$

Thus, knowing the duration of the lowering of the level t , it is possible to obtain the magnitude of floods Q_{out} :

$$Q_{out} = \Delta V_n / t \quad (4)$$

The determination of the hydrological parameters of the paleolake was carried out in the ArcGIS 10.6 software using the SRTM DEM.

3. Results and discussion

According to the conducted studies, the ridges are composed of two heterogeneous sediment strata. In the base of the ridges lies a layer of rolled boulders, pebbles and gravel with coarse-grained sand aggregate. Boulder-pebble deposits is not differentiated granulometrically, the hydraulic size varies widely – there are both boulders $d \geq 15-50$ cm ($\omega = 2.7-5$ m/s) and gravel with sand $d = 0.03-1$ cm ($\omega = 0.12-0.7$ m/s), which characterizes the variability of the hydrodynamic situation typical for fluvio-glacial flows with a flood regime. The boulder-pebble layer is covered by packs of thin-layered dense clays and siltstones of brown and light gray color ($d =$ from 0.005 mm to 0.05 mm; $\omega \leq 0.15$ m/s), clearly indicating on their lacustrine origin.

According to the results of the research, 201 shorelines were identified in the range of abs. heights of 1531-2133 meters, the height between which varies from 1-2 meters to 4-9 m. At the maximum filling level of 2133 meters, the depth of the Chuya-Kuray Lake reached 673 meters, the volume of water – 753 km³, and the area of the water area reached 3054 km² (Pozdnyakov and Pupyshev, 2020). Currently, it is assumed (Okishev and Borodavko, 2001; Agatova et al., 2020) that the formation of the lake is associated with the blocking of the flow of the basins by the Maashey glacier, but only a glacial dam would not be enough to restrain the water column over 600 m due to the presence of cracks in the glacial body. An ice dam formed by layer-by-layer freezing of ice (Pozdnyakov, 2019) would be restrain water and resistant to long-term gradual erosion. The length of such a dam was over 40 km, and the area exceeded 350 km²; the total volume of ice was 68 km³. The freezing of the ice dam was facilitated by a short warm season and low water flow due to the fact that most of the river valleys were occupied by glaciers.

The study of relative heights of shorelines (Pozdnyakov and Pupyshev, 2020) shows that the drainage of the lake was characterized by a flood regime. In the initial period of drainage, when the water area was maximum (3000-3050 km²), and the lowering of the level was 1-2 m/year, the water flow was 370-730 m³/s. Periodic peak flood water flow rates at levels with an absolute height of 2100-1700 m were 800-2120 m³/s, and taking into account the melting of dam ice (68 km³), floods reached 2160 m³/s. In general, the drainage of the lake occurred unevenly and with gradual attenuation for about 200 years (Pozdnyakov and Pupyshev, 2020).

4. Conclusions

The presence of a cover of lacustrine clays within the fields of the ridge relief of the Kuray basin suggests that it began to form in the pre-lake period in the form of fluvioglacial fan. The drainage of the paleolake occurred by overflow and erosion of the ice dam with a synchronous lowering of the water area level.

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Conflict of interest

The authors declare no conflict of interest.

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Dynamics of paleo-fires in the forest-steppe zone of the Western Siberia

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ABSTRACT. In this work we present the results of reconstruction of the dynamics of paleo-fires over the last 3300 cal. yr BP in the Barabinsk forest-steppe of the Western Siberia based on macrocharcoal analysis and radiocarbon dating of peat deposits of the Nikolaevsky ryam. The authors identified 18 local fire episodes using the CharAnalysis program. At the end of the Subboreal period, 6 local fires occurred, probably caused by dry and cold conditions. In the subAtlantic period of the Holocene, 12 fires were recorded with a peak of pyrogenic activity at 1200-1000 cal. yr BP. This peak of fires is probably associated with the warm and dry conditions of the Medieval Climate Optimum. As a result of the study, it was concluded that the intensity and frequency of paleo-fires in the area of Nikolaevsky ryam were influenced by climatic changes: in dry climatic periods, an increase in fire activity was observed.

Keywords: Western Siberia, paleo-fires, Holocene, macrocharcoal analysis, climate change

1. Introduction

Throughout the Holocene, there was a change in natural and climatic conditions, which led to the restructuring and evolution of ecosystems. Some of these changes can cause fires. But what is the scale and intensity of the fires in the past? How important is the role of climate in the occurrence of paleo-fire activity? To answer these questions, it is necessary to restore the local pyrogenic dynamics of the past. So we study swamp deposits using the method of macrocharcoal analysis (Mooney and Tinner, 2011). Peat sediments of mires are a reliable archive of paleoecological data. They store information in peat layers in the form of plant organics, palynomorphs, as well as macroscopic charcoal particles (size >100 microns) – direct witnesses of paleo-fires. The method of macrocharcoal analysis allows reconstructing the dynamics of paleo-fires on a local scale (1-3 km from the fire source). As an object of research, we chose extra zonal raised bog – “ryam”, located in the Barabinsk forest-steppe of the West Siberian Plain. The published paleoecological studies in the Barabinsk forest-steppe zone (Naumov et al., 2009; Zhilich et al., 2017; Stepanova and Volkova, 2017; Koronatova and Mironycheva-Tokareva, 2019) are mainly related to the reconstruction of vegetation dynamics and climate change during the Holocene (Zhilich et al., 2017), the study of the formation of peat deposits (Stepanova and Volkova, 2017), and also

with the study of modern climate (Koronatova and Mironycheva-Tokareva, 2019) and vegetation (Naumov et al., 2009). But no studies related to the dynamics of paleo-fires have been carried out thus far. Therefore, the aim of this work is to reconstruct the dynamics of paleo-fire activity in the Holocene on the example of the Nikolaevsky ryam of the Barabinsk forest-steppe.

2. Materials and methods

Nikolaevsky ryam (55°09 N, 79°03 E) is located within the Barabinsk forest-steppe (Ubinsky district, Novosibirsk region) in central part of the Ob-Irtysh interfluvium of the Western Siberia. Modern vegetation of mire is represented by pine-birch-shrub-sphagnum formations in the center of the ryam, and on the periphery – a hummocky-sedge-reed swamp with an abundant growth of *Betula pubescens*.

The expedition works were carried out in September 2021. Samples of peat deposits of the Nikolaevsky ryam were selected for macrocharcoal analysis (the thickness of the deposits was 320 cm) from a peat section. Since the peat of the mire is dense and waterlogged, a hollow was dug to a depth of 170 cm, from which a peat monoliths were taken for further processing in the laboratory. The heavily watered lower layers of the profile made further sampling difficult. From a depth of 170 cm to 320 cm, a core of a peat deposit was extracted using a Russian corer

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sampler. According to previously published studies (Stepanova and Volkova, 2017), the thickness of peat deposits of the Nikolaevsky ryam is more than 4 meters. In our case more deep peat was very dense and impossible for coring.

The standard method of sample processing by macrocharcoal analysis was used to reconstruct the local history of paleo-fires (Mooney and Tinner, 2011). Samples were taken with a volume of 2 cm³ with an interval of 1-2 cm in each collected peat monolith. All 170 samples of peat deposits were washed with distilled water and sifted through a 125 microns sieve. After chemical treatment of samples by Na₄P₂O₇ and H₂O₂ (Mooney and Tinner, 2011), charcoal particles in each sample were counted in the Bogorov chamber under a binocular microscope at 45x magnification.

In the radiocarbon laboratory of IMCES SB RAS (Tomsk, Russia), 5 radiocarbon UMS dates were obtained (Table). Based on radiocarbon dates calibrated in the Bacon program (Blaauw and Christen, 2011) in R 4.0.4 (R Core Team, 2020) in system “from the present time” (for zero the reference point was adopted in 1950 yr.), a depth-age model of peat deposits of the Nikolaevsky ryam was constructed and the calendar age of each sample was calculated. All further paleo-reconstructions for this peat section are based on the calibrated (calendar) age.

Statistical processing of the obtained numerical data on the number of charcoal macroparticles in the peat deposits of the Nikolaevsky ryam was carried out using the CharAnalysis software package (Higuera, 2009) adapted for the R program. This program made it possible to calculate the rate of accumulation of charcoal particles (CHAR-index), to determine background and threshold values for separating local fires (within a radius of 1-3 km from the source of ignition) from regional fires (at a distance of up to 20 km), as well as to identify local fire episodes. The data of the depth-age model of the deposits of the Nikolaevsky ryam were used as a chronological basis.

3. Results and discussion

The age of peat deposits of the Nikolaevsky ryam was 3300 cal. yr BP according to radiocarbon dating. The study thickness of peat started to form at the end of the Subboreal period in a cold and dry climate (Arkhipov and Volkova, 1994). At this time, 6 local fire episodes were identified (from 3200 to 2500 cal. yr BP) using the CharAnalysis program. The peak of pyrogenic activity occurred at 2900-2800 cal. yr BP with a charcoal accumulation rate of ~400 particles per cm²/year. These data indicate large local fires in the swamp, probably caused by increased aridity of the climate during this period.

In the Subatlantic period of the Holocene, 12 local fire episodes were identified. In the first half of the Subatlantic period (2600-1800 cal. yr BP), 3 local fires occurred with a peak pyrogenic activity at 2500 cal. yr BP and a charcoal accumulation rate of ~200 particles per cm²/year. Dry and warm conditions of this period (Arkhipov and Volkova, 1994) could

Table. Radiocarbon dates from Nikolaevsky ryam.

Laboratory Code	Sample Depth (cm)	Radiocarbon Date (¹⁴ C yr BP)
IMCES-14C2271	48-50	450 ± 100
IMCES-14C2267	100-102	1150 ± 110
IMCES-14C2266	118-120	1600 ± 105
IMCES-14C2270	150-152	1745 ± 120
IMCES-14C2269	168-170	1805 ± 150

affect the occurrence of fires. In the second half of the Subatlantic period (1800-1000 cal. yr BP) 5 local fire episodes happened. At the same time, maximal peak of fire activity occurred at 1200-1000 cal. yr BP with the highest accumulation rate of charcoal ~600 particles per cm²/year reflecting, possibly, spreading of fire on the surface of mire. These data indicate large local fires at this time. The revealed peak of fire activity coincides with a sharp increase in temperature and a decrease in precipitation of the Medieval Climate Optimum, which probably influenced the increase in fires in the swamp area. In the Late Holocene (1000 cal. yr BP – to the present day), 4 local fire episodes happened. But the activity of paleo-fires is quite low compared to previous periods, and the rate of accumulation of macrocharcoal particles reaches ~150 particles per cm²/year. Probably, the dry climate at the beginning of the Little Ice Age influenced the occurrence of 3 small local fires (600-400 cal. yr BP). The subsequent warming of the climate led to another fire episode ~100 cal. yr BP. Fires that occurred in the late Subatlantic period could also occur as a result of anthropogenic influence, since there are localities.

Conclusions

The results obtained indicate a direct influence of climate change on the intensity and scale of fire activity. New paleoecological data showed that fires in this area occurred repeatedly and of varying intensity during 3300 cal. yr BP. The main course of their occurrence was probably dry climatic conditions.

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Conflict of interest

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Origin, age and development of mountain lakes of southern Far East during the Holocene monsoon variations

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ABSTRACT. A small mountain lakes-mire complex recorded in details Holocene environmental changes controlled by monsoon intensity and cyclogenesis activity. The reconstructions were based on multi-proxy studies (diatom, botanical and pollen analyses). We studied evolution of 8 lakes, located on different altitudes (from 320 to 1600 m). The studied lakes belong to four genetic types (on ancient basalt plateaus, depressions within large landslides on ancient volcano slopes and river valleys, and nival lakes on mountain peaks). Longest records (~9720 yr) of climatic changes was restored for East Manchurian mountains. Period long-term droughts 3050–1075 yr BP was connected with weakening of summer monsoon. Studied lakes of Sikhote-Alin were formed in late Holocene. The data clearly indicated drying events caused by precipitation deficits coincided with climate deterioration. Flood recurrence and cyclogenesis activity were recorded in the lake-mire complex developed on landslides within river valleys.

Keywords: climatic changes, droughts, floods, paleolandscapes, cyclogenesis

1. Introduction

Mountain lakes represent highly dynamic paleoarchives sensitive to environmental changes, and may be considered among as main objects providing information on rapid short-term climatic shifts in the Holocene. Specific features of the evolution of mountain lakes in the southern Far East are primarily controlled by the monsoon intensity, which accounts for uneven atmosphere precipitation distribution over a year. Distinctive regional features are the prevalence of dry air masses moving from the continent in winter and oppositely directed moisture air flowing from sea to land in summer. An analysis of data obtained from lacustrine sequences of Korea, China, and Japan revealed a considerable changeability in the East Asian monsoon intensity during the Holocene (Li et al. 2011; Park et al., 2019; Yamamoto et al., 2021). Much less abundant data are available on the interrelation between the lake dynamics and monsoon circulation changes in the northern part of the monsoon region. This study was aimed at the analysis of the mountain lake evolution and environmental response to climatic changes, especially to moisture supply.

2. Materials and methods

We studied sections of eight lakes located on different elevations: paleolake (elevation 320 m) on the Shufan Plateau (East Manchurian Mts.), lakes and paleolakes on Sikhote-Alin Mts. – on Shkotovskoe (elevation 730 m) and Sergeev Plateaus (900 m), Alexeevskoe Lake on Olkhovaya Mt. (1600 m), paleolake in upper reach of the Milogradovka River (445 m) and Solontsovsky lakes (Nizhnee Lake – on 565 m and Izyubrinye Solontsi Lake – on 750 m). The lacustrine-swamp sequence were drilled using a Russian peat borer and were sampled at 2-5 cm intervals. The biostratigraphic studies included botanical, diatom, and pollen analyses performed according to standard methods. Radiocarbon dating and tephostratigraphy were used for age-depth models constructed using Bacon 2 (Blaauw and Christen, 2011). Radiocarbon dating was performed at St. Petersburg State University. Tephra B-Tm of caldera-forming eruption of Baitoushan Volcano in 946/947 AD was found in the sections of Southern Primorye and used as age marker. Microprobe analysis of the volcanic glass performed in the Khlopin Radium Institute (St. Petersburg) and Moscow State University. All ages are presented in calibrated years PB.

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3. Results and discussion

There are only small shallow lakes in the mountainous regions of the southern Far East. The lakes level fluctuates in different seasons up to complete drying up at the beginning of summer. The lake basins are filled by water in late August-September during the typhoon season. Small lakes, such as Izyubrinye Solonetsi and Nizhnee lakes, are almost completely overgrown. Lake basins are filled with peat and are swales for most of the year. Open water appears here after heavy rains. The development of the lakes proceeded as complex systems – wetlands-lakes, therefore, most of the studied sections are represented by peat.

Several types of lakes can be distinguished according to their genesis. 1) Lakes of mountain plateaus, formed due to fissure eruptions of basalts in the Miocene, occupy depressions in ancient lava flows. Now such lakes are almost completely overgrown and turned into mires. Some lakes existed throughout the Holocene. 2) Lakes formed on large landslides on the slopes of the Paleocene volcano. The age of the studied lakes is late Holocene. 3) Lakes formed by landslides in heavy rainfalls and blocking river valleys. 4) Lakes in the golets belt, which are most likely of nival origin. The development of lakes of various origins are consider below.

Lakes on mountain plateaus. The most ancient lake was found on the Shufan plateau. This is one of the first and longest records (~9720 yr) of palaeogeographic events in the mountains of southern Far East. The sediments record short-term fluctuations of climate, notably moisture, which is relatively well correlated with regional patterns reflecting summer monsoon intensity. Not only temperature background changed, but the moisture supply varied over wide limits. Four stages of higher humidity (9720-7490 yr BP; 6930-3740 yr BP; 1075-360 yr BP; the last 200 years) and 3 stages of drier climate (7490-6930 yr BP; 3740-1075 yr BP; 360-200 years BP) have been recorded. There were pronounced seasonal contrasts in early Holocene, the water being well heated in summer. The hydrological regime in the depression changed drastically about 7630 yr BP. Since then prolonged dry seasons alternated with occasional rainfalls, and the groundwater feed gained in importance in the water supply to the lake. A hypnum bog appeared around the lake, on the drained areas. Herb-dominated communities developed there since the Holocene optimum. In the late Holocene the reduced moisture supply led to the shrub layer development over the swamp. An increase in aridity was recorded at ~3740 yr BP, beginning from the cooling ~3050 yr BP the driest environments set in and persisted to 1075 yr BP, that well correlated with regional patterns reflecting summer monsoon intensity (Li et al., 2011; Park et al., 2019). At the Medieval Holocene Optimum the water influx into the depression increased sharply, the more so since 940 yr BP. The Little Ice Age was also humid. The maximum water input into the depression has been recorded in the last 200 years.

On Sikhote Alin plateaus shallow lakes with swampy coasts existed during late Holocene. There are several stages recognizable in the lake evolution. The maximum depth of Skotovskoe Plateau paleolake was about 4480–3490 yr BP, under conditions of heat and moisture supply greater than at present. A short period of waterlogging is dated to ~ 3490–3380 yr BP. At its final stage there were alternating phases of flooding and shallowing, with a general tendency toward waterlogging. Between 3010 and 2630 yr BP the lake area was notably reduced and the herbaceous–dwarf-shrub–sphagnum swamp took its place; within the swamp a few small shallow lakes could persist until the last 240 years, when the water supply was essentially lessened. At present, there is a landscape facies of reed-sphagnum swamp facies in the place of the paleolake, with isolated low-stemmed larch trees. In the marginal part of the swamp the peat accumulation started ~ 4480 yr BP. Since then the swamp passed several episodes of flooding and drying. Unstable climatic conditions 4900 yr BP determined most of the features of the hydrological regime of the paleolakes of Sergeevskoe Plateau. Reduced groundwater level and a greater role of atmospheric precipitation were usually related to cold events.

Lakes on landslides on ancient volcano. Development of Izyubrinye Solonetsi Lake that formed 4400 yr BP and Nizhnee Lake (2600 yr BP) were metachronous due to different altitudinal positions. Organogenic deposits accumulated at high rates (up to 1.9 mm/yr). Nizhnee Lake response more sensitively to climatic changes. Frequent changes in diatom assemblages and peat-forming plants indicate unstable hydroclimatic conditions. A lake with a mesotrophic-eutrophic regime became oligotrophic-mesotrophic ~2330 cal. BP, had maximum depth and productivity ~2280–2110 yr BP; became oligotrophic ~2110 yr, and from 1760 yr BP - oligotrophic-dystrophic. A significant decrease in the lake level has been observed in the last millennium. Coolings were accompanied by a decrease in moisture, but the Little Ice Age was wet.

Lakes on landslides within river valleys. Lake-mire system in the Milogradovka River valley existed last 3400 yrs. Long dry events coincided with global coolings and the weakening of the East Asian monsoon. Compared to the swamps of the main Sikhote-Alin watershed and plateaus, cyclogenesis activity was recorded in the peat bog section more detail. Separate large floods also occurred during dry periods, probably in the summer-autumn season and were caused by the passage of typhoons and deep cyclones. Under conditions of more frequent floods and regular flooding, the swamp in the valley became more humid.

Nival lakes. Alekseevskoe Lake is located on the flattened peak of Olkhovaya Mt. within the permafrost-nival depression (width up to 100 m). We assume that the lake was formed during the Little Ice Age (^{14}C -date 370 ± 70 yr BP, 410 ± 70 cal yr BP, LU-7709), which was wet. The lake level was not constant. The maximum level was in the second half of the Little Ice Age (XVI-XVIII centuries), which may correspond to humid cold conditions in the upper mountain belt.

4. Conclusions

Small mountain lakes in the southern Far East are sensitive paleoarchives of moisture changes, mainly controlled by summer monsoon intensity and cyclogenesis activity. The longest periods of long-term droughts were identified in the southernmost Primorye. In Sikhote-Alin at higher altitudes, the dry phases were shorter and coincided with cold events. The Little Ice Age was a wet with frequent fluctuations in temperature and moisture.

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Conflict of interest

The authors declare no conflict of interest.

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Study of Holocene aeolian morpholithogenesis of the Eastern coast of the White Sea using georadiolocation and palaeolimnological methods

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ABSTRACT. Holocene aeolian topography and sediments were investigated at two key sites on the Zimny Coast and one key site on the Kaninsky Coast of the White Sea. Field work included ground penetration radar profiling, paleolimnological and geomorphological study, as well as aerial imagery and topography surveys. Analytical studies including grain-size, geochemical and diatom analyses and radiocarbon dating of lake sediment cores were performed. Accumulative aeolian relief was formed in areas with a positive coastal-marine sediment balance. The sands are brought in by a longshore drift or river discharge. The aeolian topography and the number of stages of aeolian activation vary across the key areas. The present-time coastal dunes have been forming since the late or middle Holocene, when relative sea level became close to contemporary levels.

Keywords: aeolian morpholithogenesis, Holocene, palaeolimnology, White Sea, Zimniy Coast, Kaninsky Coast

1. Introduction

Aeolian processes are among of the most important components of coastline morpholithogenesis of the World's Oceans (Vyhovenets, 2003; Sloss et al., 2012). The shape and dynamics of coastal aeolian relief depend on a complex combination of factors. The most important of these are the sediment balance in the coastal zone, the direction of the prevailing winds relative to the coastal line and the changing configuration of coasts. The activation rhythms of coastal aeolian processes depend on the relative sea level (RSL) and the regime of winds, waves and fast ice changes. Despite a long period of study of coastal dunes and foredunes, including on the Arctic shores (Ruz and Hesp, 2014), the response of coastal aeolian processes to changes in the natural environment remains a subject of debate (Badyukova and Solovieva, 2015). On the shores of the White Sea, this problem had hardly been studied. Our studies are aimed at obtaining actual data on the aeolian relief and rhythms of activation of aeolian processes on the Eastern coast of the White Sea after deglaciation.

The largest areas of Holocene aeolian landform development are located in the sites of coastal accumulation. These are estuaries or areas of divergence coastal sediment flows. The first data on the aeolian topography and deposits have been obtained at the three key sites - from Intsy to the mouth of the Ruch'i River and in the region of the mouth of the Maida River (Zimniy Coast) as well as at the mouth of the Shoina River (Kaninsky Coast).

2. Materials and methods

The research methodology involves the geophysical (GPR), paleolimnological, geodesic (UAV and DGPS surveys), geomorphological, analytical (geochemical, micropaleontological) and geochronological (radiocarbon and OSL dating) methods. This allows for a comparative analysis of the modern and relict coastal aeolian landforms and sediments with the lithological and stratigraphic sequence of bottom sediments of coastal lakes or peat bogs, located in the zone of aeolian transport.

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GPR profiling is carried out using Zond-12e GPRs and OKO (antennas with frequencies ranging from 50 to 400 MHz). This allows the characteristics of the sediment sections to be obtained to a depth of up to 20 m. Radarograms are processed in Prism 2.5-2.7 software, RadExplorer 1.42 and GeoScan32. Interpretation of radarograms is based on wave pattern analysis according to the methodology (Starovoitov, 2008) taking into account coring data.

Geodesic profiling is carried out using DGPS PrinCe i50, aerial photography quadcopters DJI Phantom 4 Pro v2.0. and DJI Mini2. As a result, orthophoto images and digital elevation models were produced. These are used for altitude referencing of GPR profiles, calculation of aeolian volumes and production of terrain morphodynamics maps.

Geomorphological studies include interpretation of multi-temporal satellite and aerial images, profiling of coastal terraces, and analysis of the landforms and dynamics of the modern coastal zone.

Coring of lake and peat bogs deposits is performed using a Russian peat corer (sampler diameter - 5 cm, length - 100 cm). The sediments sampling was performed from the ice in spring and from a platform in summer.

The coring is accompanied by lithological and stratigraphic description of cores according to the methodology (Subetto, 2009) and core sampling for analytical studies. Cores were taken in 1 m long plastic halfpipes. Analytical studies and dating of lake-bogs sediments provided information on RSL changes and rhythms of aeolian process activation.

3. Results

In the area from Intsy Cape to the mouth of the Ruch'i River (Zimniy Coast) the Holocene coastal dunes were formed in three sites.

On the right bank of the Ruch'i River, dunes were ~2 km long, ~0.3 km wide and 4 m high. The dunes overlapped the sand spit and slopes of moraine ridges. Two aeolian sand horizons on the GPR profiles were identified. Their thickness increases from the root to the distal end of the spit. However, in the sediments of the paleolagoon the aeolian sand are distributed evenly.

In the northern part of the Intsy accumulative cape, dunes were located to the inner edge of the Holocene marine terrace. The dunes were ~5.5 km long, 0.2-0.5 km wide and relative height up to 10 m. GPR profiles here also show two horizons of aeolian sands. Their thickness increases in the area where sediments fall out of the longshore drift (Lugovoy and Repkina, 2019).

To the south of Cape Intsy, dunes were developed in the paleostrait between moraine ridges. The paleostrait is filled with sediment from two small rivers. Dunes were 0.1-0.5 km long, up to 50 m wide and up to 2 m relative height. They move in the direction of the prevailing winds - from the rivers towards the sea coast.

At the mouth of the Maida River (Zimniy Coast) dunes (~3 km long and up to ~1.5 km wide) were developed on the sand spit. The height of the foredunes rises from 1-2 m at the root of the spit to 4-5 m at its distal. Further out from the sea, four dune ridges (5-18 m height), were traced parallel or at an angle to the modern coastline. The internal structure of eolian sands on GPR profiles becomes more complex with distance from the sea coast. Thin layers enriched with aeolian sand were found in the peat deposits of the swampy palaeolagoon.

On the mouth-spit of the left bank of the Shoina River (Kaninsky Coast) dunefields ~8 km long, up to ~0.6 km wide and up to 22 m in relative height are developed. They consist of four dune ridges, parallel to the coastline of the sea. In their turn the ridges consist of individual dunes, which run almost perpendicular to the seashore and parallel to the river bank. GPR profiles show the complex internal structure of the dunes. The number of aeolian sand horizons increases with distance from the seashore and river mouth.

4. Discussion

The age of the dunes has not yet been determined. It can be assumed that they began to develop on the Zimny Coast simultaneously with low marine terraces - after ~4.7-4.3 ka BP (Repkina et al., 2019; Shilova et al., 2019) and are still being formed. Large horizons of aeolian sands, which we see on GPR profiles, probably correspond to the stages of intensification of aeolian processes. The age of these horizons can be most easily determined by dating the sand-enriched paleolagoon sediments.

5. Conclusions

In the key areas studied, the coastal dunes were formed by sediments that come from two main sources. In the areas of river mouths of the rivers Ruch'i, Maida and Shoina, and also on Cape Intsy, the main source of sand is the longshore drift. Whereas in the paleostrait south of Cape Intsy, the main source of sand is river. The internal structure of dunes and the number of stages of aeolian activation are different at the key sites. The present coastal dunes have been formed since the Late or probably since the Middle Holocene, when the RSL became close to the contemporary level.

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Conflict of interest

There is no potential conflict of interest.

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The relative sea level changes and aeolian processes on the Eastern coast of the White Sea (Gorlo Strait) during the Late Glacial and Holocene (based on studies of Lake SrednyayaTret')

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ABSTRACT. Geomorphological, ground penetration radar profiling and paleolimnological investigations were carried out in the Lake SrednyayaTret' (66.014009°N, 41.086294°E; 7.3 m ASL). Bottom sediments from the three boreholes were studied. Lithostratigraphic description, grain-size and diatom analyses were carried out, loss on ignition, C_{org}/N_{org} was determined. Radiocarbon ages were obtained from the lower horizons of post-glacial sediments. Signs of Late Glacial transgression (earlier ~12.1 kyr. cal. BP) and Early Holocene regression (started between ~12.1 and ~10.3 kyr. cal. BP) were determined. The next filling of the lake basin can be compared with the Middle Holocene transgression. At the same time sea waters did not penetrate into the lake basin. The beginning of this stage was apparently accompanied by intensification of coastal aeolian processes.

Keywords: RSL, aeolian processes, palaeolimnology, grain-size analysis, diatom analysis, loss on ignition, C_{org}/N_{org} , Late Glacial, Holocene, White Sea, Gorlo Strait

1. Introduction

Gorlo Strait is a key area for understanding the White Sea level dynamics after glaciation degradation. It is also an area with strong winds and active coastal aeolian processes (Repkina et al., 2019). In recent years, the age of ancient coastal lines on the southeastern coast of the Strait has been established and the main features of relative sea level (RSL) during the Holocene have been determined. The RSL stabilization (~7.3 - ~3.1 kyr. cal. BP) at levels above modern was determined (Repkina et al., 2019; Shilova et al., 2019; Zaretskaya et al., 2020). The distribution of Holocene marine sediments has been traced by diatom analysis up to 4 m a.s.l. (Shilova et al., 2019). The coastal landforms (beach ridges and spits) traced up to 5-7 m a.s.l. (Repkina et al., 2019). Differences in the height of RSL indicators require explanation. The timing and level of Late Glacial transgression and the relationship between RSL changes and rhythms of Aeolian processes

also remain under discussion. The first results from the study of Lake SrednyayaTret' add to the evidence to solve these issues.

2. Materials and methods

Lake SrednyayaTret' (7 m a.s.l., 66.014009°N, 41.086294°E) is located on the eastern coast of the White Sea (Gorlo Strait) between the Intsy cap and the mouth of the Ruch'i river. A diameter of lake about ~1 km and depth about ~1.9 m. The lake basin is bounded by smooth moraine ridges and sandy eskers (10-32 m). The lake basing is drained by a channel which inflow into the estuary of the Ruch'i River in 10 km upstream of its mouth. According to the relief of the basin, if the RSL rose above the lake's threshold, it became part of the estuary. The salinity of the water must have been less than in the open sea. And if the RSL did not reach the lake's threshold, transgressions could only affect

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the lake by changing the hydrogeological situation. These events could be recorded by geochemical and micropaleontological indicators. Therefore, the Lake SrednyayaTret' is an ideal site for RSL studies.

Field investigations included DGPS and surveys, geomorphological and ground penetration radar profiling (GPR) and coring of the lake sediments.

Coring was carried out from the ice using a Russian peat corer at 4 points (ST1-ST4). It was accompanied by lithological and stratigraphic description according to the methodology (Subetto, 2009) and core sampling for analytical studies and radiocarbon dating. GPR studies were carried out using Zond-12e ground penetrating radar and 300 MHz antenna (average depth - up to 10 m, resolution - first tens of centimeters). The first results of core analyses were obtained. For samples from lower horizons of cores from core sections ST2, ST3 and ST4, grain-size, loss on ignition, Corg/Norg were determined. The sediment dating core was done in the Laboratory of Radiocarbon Dating and Electron Microscopy of the Institute of Geography, RAS, and the Center for Applied Isotope Studies, University of Georgia, USA, according to the procedures adopted in these laboratories.

3. Results

Radarograms show the surface of the lake bottom, uneven basin and layered sediments between them. On the sides of the basin and above the glacial ridges, the thickness of layered sediments does not exceed 0.5 m; in depressions between the ridges, it increases up to 4 m.

The lake sediment sequence is fully penetrated by ST2 core section (water depth 183 cm, sediment thickness 457 cm), which is located in the center of the basin. Core sections ST1 (water depth 145 cm; sediment thickness 19 cm) and ST3 (water depth 152 cm; sediment thickness 200 cm) were cored on the sides of the basin. Core section ST4 (water depth 120 cm; sediment thickness 35 cm) was cored on the moraine ridge.

Four lithostratigraphical sequences (units) in the lake sediments have been identified. These units have a slight difference in lithology and sediments thickness in core sections:

Unit 1. The bottom sediments are silty-clay or silty-sand (2-30 cm) with LOI less than 5% and a Corg/Norg ratio of <10 to 10.3. According to (Lamb et al., 2006), Corg/Norg values <10 are typical for marine sedimentation conditions. No diatoms were found. According to radiocarbon age from the core ST2, the sediments were formed earlier than ~12.1-12 kyr. cal. BP.

Unit 2. In the most complete sections (ST2 and ST3), the Unit 1 sediments recovered by peaty gyttja layer (36-51 cm). The age of the basing layer (core ST2) is ~10.3 kyr. cal. BP. The mineral part of this unit is represented by silt and clay. LOI content varies from 40 to 95% and Corg/Norg values from 11 to 37. Diatoms are represented by lake-swamp species in the lower

part of the core ST2 and it is replaced by lacustrine species in the upper part.

Unit 3. On the western side of the lake basin closer to the seashore (borehole ST3), interbedded dense sandy silts and silts with plant remains (48 cm) lie on the peaty gyttja. In the centre of the lake (borehole ST2), the horizon is represented by sandy gyttja with plant remains and thin interlayers of sand (46 cm). The sand grains are poorly rounded and unrolled. In the core from the core ST3, the LOI ranges from ~2 to 24% and the Corg/Norg value varies from 52.9 to 19.2. At the base of the layer (contact with the peaty gyttja) Corg/Norg drops sharply to 5, which is typical for marine sediments (Lamb et al., 2006). Diatom content is uneven. Lacustrine and swamp diatom species are present in layers of sand enriched with fine organic material. In the sand and coarse detritus diatoms are absent.

Unit 4 and Unit 5 are represented by typical lake sediments - dark brown to olive gyttja (up to 238 cm), and silt (up to 49 cm). The sediments contain sands, silt and reare plant remains.

Unit 6. At the depth of about 1 m and up to 2 m from the open sea shore, the modern lake sediments are represented by fine-grained sands. They are uncovered by core ST1. The sands enter inside the lake due to erosion of its shores and with aeolian flows. The sources of aeolian sands are beaches of the open sea shore and glacial deposits.

4. Duscussion

Unit 1 can be compared to post-glacial transgression. Extremely organic-poor sediments accumulated up to ~12.1-12 kyr. cal. BP. Probably, in the conditions of an isolated bay of the Ruch'i River estuary. Probably, there was a glacier margin. The data obtained correspond to the transgression dates (~13-11.5 kyr. cal. BP) established for the White Sea (Kolka and Korsakova, 2017).

Unit 2. The beginning of the formation of peat deposits (between ~12.1-12 and ~10.3 kyr. cal. BP) is probably associated with bog development in the previously dried basin. The atering of the basin gradually increased, and a stable freshwater reservoir was formed. At the end of the stage, the lake level seems to have been lowered. In the center of the basin (core ST2) diatom associations correspond to lacustrine conditions and at its periphery (core ST3) was overgrown shallow area. Unit can be compared with a late-glacial regression. It is dated in the western part of the White Sea by the interval ~11.5-9.8 kyr. cal. BP (Kolka and Korsakova, 2017). On the eastern coast of the sea, peat with an age of ~10.6-8.5 kyr. cal. BP is correlated with the regression (Repkina et al., 2019; Shilova et al., 2019; Zaretskaya et al., 2020).

Unit 3. The formation of the interval can be associated with the end of the Early Holocene regression and the beginning of the Middle Holocene transgression. The sharp decrease in the Corg/Norg values at the base of the horizon (core ST2) may be a

sign of short-term intrusion of sea waters into the lake basin. However, diatom associations do not confirm it. The filling of the lake basin continued, possibly due to hydrological situation caused by an increase in RSL. On the margin of the basin, close to the open sea, the interstratification of sandy and peaty sediments indicates, possibly, a periodic activation of aeolian transport from the beaches.

Unit 4 and Unit 5 were formed in lacustrine conditions, probably during the mid-late Holocene.

5. Conclusions

The bottom sediment section of Lake SrednyayaTret' reveals traces of Late Glacial transgression that ended later than ~12.1 kyr. cal. BP and regression of the Early Holocene (started between ~12.1 and ~10.3 kyr. cal. BP). The next filling of the lake basin can be compared with the Middle Holocene transgression. However, the assumed by morphological data increase of the RSL to 6-7 m is not confirmed by the results of analytical studies of the lake bottom sediments. Due to the increase in RSL, the shoreline of the sea approached the lake basin. In the bottom sediments this is recorded by interlayers of sand, which, as at present, is brought by wind from sandy beaches.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Seasonal sedimentation in saline Lake Shira (Siberia, Russia) and meromixis: implications for regional paleoclimate reconstructions

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ABSTRACT. Detailed studies of processes of sediment record formation are necessary for accurate sediment-derived paleo-environmental reconstructions. We conducted the multi-year seasonal sediment evolution of sediment fluxes of chemical elements, organic and inorganic carbon, total nitrogen, and photosynthetic pigments for a period from 2012 to 2017. In 2013, 2016, 2017, and 2018, we estimated the contents of photosynthetic pigments in the uppermost sediment layers frozen in situ with a freeze-corer. In 2015 and 2016, a rare event of transition from meromixis (i.e. long-term hypolimnetic anoxia) to holomixis was observed, which was accompanied by the temporary disappearance of hydrogen sulfide from the water column in spring and a decrease in hydrogen sulfide in other seasons compared to the meromictic state. We have demonstrated that okenone and Mo in the Lake Shira sediments reflect the presence of hydrogen sulfide in the water column. However, the okenone showed smoothed multi-year dynamics without a pronounced seasonal one. Therefore, the okenone can be a proxy of sulphidic conditions in photic zone and weakly depend on seasons whereas Mo can be used as an indicator of winter periods when analyzed in cores with annual resolution. Sedimentation fluxes of other substances showed typical seasonal dynamics with a minimum in winter and a maximum in late summer and autumn. All chemical elements in the sedimentation flow can be roughly divided into those associated with organic matter and terrigenous-chemogenous. The components of the second group showed a pronounced peak of sedimentation in autumn 2012 and summer 2017 presumably due to the increased amount of precipitation at that time. This demonstrates the relationship between the terrigenous components and the climate humidity for this lake. Besides, it reflects the irregularity of annual varves composition.

Keywords: meromictic lake, sediment traps, stratification, okenone, molybdenum, XRF analysis, holomixis, climate change

1. Introduction

Accurate lake sediment-derived palaeo-environmental reconstructions require in-depth knowledge of sediment record formation processes. This might be achieved only by a combination of comprehensive monitoring and sediment trap study (Apolinarska et al., 2020). Since the change in mixing regime results in the changes of the sediments composition, the alterations between meromixis and holomixis can be reconstructed for the long period of a lake history (Vegas-Vilarrúbia et al., 2018). However indisputable sediment proxies of hypolimnetic anoxia

and meromictic conditions are still scarce (Sorrel et al., 2021).

2. Materials and methods

Lake Shira (N 54.30, E 90.11) is located in south of Siberia, in the North-Minusinsk Valley Lake Shira has an elliptical shape, the size of 9.35×5.3 km, the water surface area of 35.9 km², the average depth of 11.2 m, and the maximum depth of 24.5 m (2007-2019). The sediment traps were deployed seasonally from 2012 to 2017 in the central deepest part of the lake at the depth of 20 m. The samples of the uppermost

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undisturbed sediments were retrieved using a pump freeze-corer made in the workshop of the Institute of Biophysics (Krasnoyarsk, Russia) after Renberg and Hansson (1993). Freeze-coring was carried out in March 2013, 2016, and 2017 and February 2018 from the ice surface. The carotenoids in the traps and sediments were determined by high-performance liquid chromatography (HPLC). Total carbon and total nitrogen were determined using FlashEA 1112 NC Soil/MAS 200 CN elemental analyzer (ThermoQuest, Italy). The elemental composition was measured in solid blocks of sediment material using micro-XRF analysis by Synchrotron radiation (scan XRF SR) in the Institute of Nuclear Physics (Novosibirsk, Russia) (Kalugin et al., 2013).

3. Results and discussion

During 2012-2014, the lake was meromictic and winter mixing did not reach the bottom. In the spring of 2015, the water column was mixed and reached the bottom, and hydrogen sulfide disappeared completely of the water column but reappeared there in summer. In May 2016, the almost complete mixing was observed again. Thus, during 2015-2016, the lake was holomictic. However, in 2017, the spring mixing did not reach the bottom, so the lake became meromictic again and remained meromictic during 2018 – 2022. The sulfide content in the water column was relatively high in 2012-2014 compared to 2015-2016, when other increasing occurred in 2017. Therefore, the sulfide content reflected the changes of the lake mixing regime. Principal component analysis showed that the main differences in contents of the traps were associated with the season. Nitrogen, organic components (carotenoids, Chl-*a* and organic carbon), Br, Cu, As, S, Cl, and Zn constitute one large group, whereas other large group consisted of Cr, Pb, Ca, Ni, Zr, Rb, Nb, Ga, Y, Sr, Th, V, K, Ti, Mn, Fe, and inorganic carbon. Molybdenum was a single component that was clearly confined to the winters, while Bchl- *a* and okenone were merged into a separate group. These are specific pigments of purple sulfur bacteria (PSB), so their dynamics reflected the dynamics of PSB described elsewhere (Rogozin et al., 2017). The content of these pigments in the traps was the greatest in 2012 and decreased throughout the entire study period. Organic carbon, Chl-*a*, and carotenoids of oxygen photosynthetic organisms (lutein + zeaxanthin, alloxanthin, beta-carotene) in the traps demonstrated regular seasonal fluctuations - minima in winter and spring and a noticeable increase in summer and autumn. In contrast, neither okenone nor Bchl-*a* demonstrated seasonal dynamics.

In frozen recent sediments, a steady downward trend in the annual okenone content was similarly observed with traps. In contrast, the contents of Chl-*a* and other carotenoids increased slightly from 2016 to 2018. The use of the freeze-corer allowed us to see the structure of the recent sediments changed from laminated to homogeneous after 2013. We assume the decrease in monimolimnetic stability enhanced

the movement of bottom water and, hence, led to resuspension of the uppermost sediments. The color transitions in the traps corresponded generally to the typical alternation of light and dark layers described for other lakes. However, using sediment traps, we revealed a violation of the typical alternation of colors: in 2012, the color of the sediment in the autumn trap was light, while in the autumn periods of other years it was dark. The light color in autumn 2012 coincided with a higher content of inorganic carbon and all terrigenous components. Presumably the large amount of terrigenous matter was carried into the lake after abnormally high precipitation in August 2012. Thus, we demonstrate that weather anomalies can cause irregularities in the formation of annual varves.

4. Conclusions

In general, we did not reveal any noticeable differences between the meromictic and holomictic states in the composition of sediments, except okenone. We demonstrated okenone and Mo reflect the presence of hydrogen sulfide in the water column in Lake Shira sediments. However, okenone showed smoothened multi-year dynamics and no distinct seasonal dynamics. Therefore, okenone can be a proxy of sulfidic conditions in the photic zone and is seasonally invariable whereas Mo can be used as an indicator of winter periods when analyzed in cores with annual resolution. The obtained results will be useful for down-core analysis of the bottom sediments aimed to reconstructing the stratification regimes of Lake Shira and climate changes in the south Siberia.

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Conflict of interest

The authors declare no conflict of interest.

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Terrestrial vegetation and lake aquatic communities diversity under climate change during the mid-late Holocene in the Altai Mountains (Ulagan plateau) based on the pollen and cladocera data

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ABSTRACT. The present study is focused on the reconstruction of plant and cladocera diversity in the paleo-record of Lake Balyktukel (Ulagan Plateau) for the past 7 kyr.

Keywords: pollen, cladocera, climate, biodiversity, vegetation, Holocene, Altai

1. Introduction

The issue of global biodiversity decline has recently been actively discussed in both scientific and public communities. Mountain regions with high biodiversity are of interest for investigations on the biodiversity change and causes that affect biodiversity (Rudaya et al., 2021). Lake sediments containing proxies such as pollen and remains of organisms that lived in the lake can be analysed using statistical methods and at a high resolution. The taxonomical composition of lacustrine biotas such as cladoceran can provide valuable information not only about environmental changes in the lakes but also about biodiversity changes and species turnover over time. Pollen data is an important proxy for studying the terrestrial vegetation biodiversity over long time scales (Birks et al., 2016; Felde et al., 2020; Rudaya et al., 2020; 2021).

The main objective of this study is the reconstruction of plant and cladocera diversity in the paleo-record of Lake Balyktukel (Ulagan Plateau) for the past 7 thousand years.

2. Materials and methods

The studied object - Lake Balyktukel (N 50.53°, E 87.70°, 1842 m asl) is located on the high-mountain

Ulagan Plateau in the northeastern part of the Altai Mountains. Bottom sediment core *BK2018-1* (2.35 m, 50.53411 N, 87.70788 E) was sampled in 2018 with a gravity corer from the lake's deepest point of 23.9 m. The age-depth model is based on the 12 radiocarbon dates obtained from bulk sediments; pollen and cladocera analyses were provided for the paleorecord. The richness and diversity of all bioproxies were calculated as the effective taxon numbers of Hill (Hill, 1973). DCCA with species assemblage changes constrained to sediment age as the sole environmental variable, was used to develop quantitative estimates of compositional turnover, scaled in standard deviation (SD) units for each taxonomic group (according to Birks, 2007).

3. Results and discussion

The core, according to the age-depth model, covers the last 6.95 kyr. The rate of sedimentation is estimated at 0.35 mm per year.

The pollen record covering the last 6.95 kyr BP can be divided into three pollen zones. PZI (237-150 cm; 6.95-4.3 kyr BP) is characterized by a dominance of *Pinis sibirica* and *P. sylvestris*; a slightly higher percentage of *Betula* and *Amarantaceae*, and a slightly lower abundance of *Poaceae* than the overlying PZII. PZI is also characterized by the abundance of green algae

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Botryococcus remains, which may indicate a warming of the reservoir. PZII (150-85 cm; 4.3-2.2 kyr BP) is characterized by a slight increase in the abundance of Poaceae, a slight decrease in *Picea* pollen, and a marked decrease in the abundance of *Botryococcus*. Stomata of *Larix* are found in this zone. Pines also dominate in this zone; after 3.3-3 kyr BP, *Pinus sylvestris* increases its abundance, and the percentage of *Betula* sect. *Apterocaryon*, on the contrary, decreases. PZIII (85-0 cm; 2.2 kyr BP - AD 2018) is characterized by a slight decrease in the share of arboreal pollen, a slight decrease in the abundance of *Abies* pollen, and an increase in the abundance of Poaceae. Pines also prevail in this zone; evidence of presence of pine and fir close to the lake is finding their stomata in this zone. *Betula* sect. *Apterocaryon* increases slightly after 0.5 kyr BP.

Alpha-diversity indices of the terrestrial plants based on the pollen reveal large amplitudes among dominant (N2) and common (N1) species. The highest N1 and N2 indices are observed in the interval of 6.95-3.7 kyr BP. The indices of plant diversity increase 0.4-0.2 kyr BP that can be attributed to the Little Ice Age. The calculated pollen diversity indices show significant positive correlations with the calculated amount of annual precipitation (not published) at the N1 and N2 levels.

Taxonomic diversity relative to the time gradient (species turnover) based on the pollen data has relatively high values from the beginning of the paleorecord to about 3.2 kyr BP with maxima at 6.2 kyr BP (0.7SD) and 3.3 kyr BP (0.6 SD). Thereafter, the indices decrease to the minimum and only in the last 0.8 kyr BP increases steadily. The period between 3 and 1 ka BP beta-diversity indices are minimal.

Twenty-four Cladocera taxa are encountered from the sediment profile, of which 17 relate to Chydoridae, other to *Daphniidae*, *Bosminidae*, *Euryercidae* and *Ophryoxidae*. The most cladoceran assemblages are dominated by *Daphnia longispina* agg. Pelagic organisms dominate the record in abundance. The stratigraphy was divided into five cladoceran zones (CZ). CZI (234-212 cm; 6.95-6.2 kyr BP) is characterized by the dominance of pelagic taxa *Daphnia longispina* agg. and *D. pulex* agg.; the littoral taxa have a maximal abundance. Toward the top of the zone, the increase of littoral phytophilous macrophyte-associated *Alonella nana* and *Alona guttata/rectangular* is observed. Only in this zone, littoral cladoceran species *Leydigia leydigia* and *Alona quadrangularis* have a constant high abundance. This period seemed more productive than the upper zones, according to the higher relative abundance of cladoceran species related to the meso-eutrophic condition (*L. leydigia*, *A. quadrangularis*). *Daphnia longispina* agg. is dominated in CZII (212-146 cm; 6.2-4.2 kyr BP), whereas *D. pulex* group decreases to very low values to the upper part of the zone. *Alonella nana* and *Alona guttata/Coronatella rectangular* are present at lower abundances. Percentages of *Alona intermedia* increase; *Oxyurella tenuicaudis* and *Alona guttata tuberculata/Coronatella rectangular pulchra* occur in this zone. It is recorded a slight increase in the

proportion pelagic/littoral taxa. In CZIII (146-80 cm; 4.2-2.0 kyr BP) *Daphnia longispina* increases *Alonella nana* is steadily present in all the layers CZ. Abundance of *Alona affinis* in the community begins to increase slightly, while the value of pelagic *Daphnia pulex* decreases to very low values. CZIV (80-16 cm; 2.0-0.3 kyr BP) is characterized by the largest species diversity. *Daphnia longispina* gr. is still dominant. The secondary species is *Alona guttata/Coronatella rectangular*. The small *Alonella nana* decreases distinctly and *Alona affinis* increase slightly towards the top of the zone. A most considerable dramatically change occurred in CZV (16-0 cm; 0.3 kyr BP- 2018 CE) in the planktonic cladoceran assemblages. Dominant in all previously zones, *Daphnia longispina* agg. begins to decrease to near extirpation in the uppermost layer and a respective rise occurred in *B. longirostris*, a small planktonic cladoceran common also in the littoral zone. Especially the abundance of the taxon increases in the upper samples of the core (up to 96%) related to the 20th century.

Alfa diversity of cladocera based on the Hill numbers reveal highest values at ca 6.5 kyr BP and about 0.12 kyr BP (1830 CE); the lowest value is noted on modern time when community becomes monodominant. Relatively low values of N1 and N2 are recorded about 1.53 – 1.2 kyr BP. Beta diversity in above 1 SD from the beginning of the record and to ca 1.8 kyr BP. The maximal meaning of species turnover is about 6.7 kyr BP (1.8 SD).

4. Conclusions

Alfa diversity of pollen taxa show positive correlation with the amount of precipitation but pollen record has not shown any significant species turnover during the last 7 kyr. The cladocera diversity shows a different pattern of biodiversity change with a significant change in taxonomic composition from the beginning of the paleorecord to 1.8 kyr BP.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Conditions of sedimentation in the Sarskoye Swamp (Yaroslavl region, Russia) in the Late Glacial and Holocene

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ABSTRACT. A comprehensive lithological analysis of bottom sediments from the central part of the Sarskaya depression was carried out. We determined that a shallow lake existed in the Sarskaya depression as least from 22500 to 12400 years ago. The bottom sediments potentially contain traces of global climate change - in particular, a presumable trace of the Bølling-Allerød interstadial has been established in sediments formed about 13500 years ago. There are signs of activation of erosion processes during the period from 13100 to 12400 years ago. Since the time the sediment condition stabilized and the water body began to swamp.

Keywords: Quaternary sedimentary archives, Holocene, Pleistocene, Sarskoy Swamp, East European Plane

1. Introduction

The Sarskoye Swamp is an oval basin with length 1.8 km and width 2.5 km and 35–40 m depth. It is located on the Borisoglebskaya Upland in the marginal zone of the Moscow glaciation and was not affected by the Last Valdai glaciation. The Sarskoye Swamp is located at the interfluve, has a limited catchment and feeding only atmospheric precipitation. In this reason, its deposits represents a detailed sedimentary paleo-archive of the Late Pleistocene and Holocene and can serve as a reliable basis for paleogeographic reconstruction.

2. Materials and methods

In 2021 a reconnaissance survey of the Sarskoye Swamp was carried out. We drilled the slopes and the central part of Sarskaya depression with a Livingstone piston sampler. A core with a total length of 19.35 m was taken. The grain size analysis, LOI and magnetic susceptibility measurement were carried out. Radiocarbon dating of ten samples was also performed in the Laboratory of Radiocarbon Dating and Electron Microscopy of the Institute of Geography of the Russian Academy of Sciences. Using the available radiocarbon dates and correlation with the oxygen isotope curve of the NGRIP GICC05 glacial core, an age-depth model was created in the Rbacon program. In addition, the species composition of diatom associations was determined for

8 samples from an interval from 770 to 970 cm of the core.

3. Results

The drill profile made on the northern side of the basin confirmed the glacial origin of the surrounding hills. We also found out that low terrace-like surfaces (0.5-1.5 m above the level of the peat surface) are composed by moraine deposits.

The age of sediments from the lower part of the core, according to the results of radiocarbon dating, is 22349-22625 cal. years ago. Thus, the sampled core represents a detailed sedimentation archive of the center of the East European Plain for the last 22000 years.

It is possible to distinguish 5 stages of the development of the Sarskaya depression (age estimation inferred from the age-depth model):

1. 22500-14800 years ago (1935-900 cm of the core). The grain size composition is quite similar throughout the depth, silt dominates 75-80% from the total, the content of sand is about 5-7%, the content of clay is 20%, the content of organic matter and carbonates is about 3-5%.
2. 14800-14300 years ago (900-800 cm of the core). The content of silt is about 74 – 78%, the content of sand slightly increases to 8-10%, the content of clay decreased to 8-12%. The content of organic matter and carbonates does not change.

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3. 14300-13100 years ago (800-640 cm of the core). The content of silt varies from 62 to 78%, the content of sand decreases to a few percent, the content of clay increases to 20-35%. The content of carbonates is about 3-6%, the content of organic matter increases from 6% at the depth 800 cm to 20% at the depth 640 cm. It is noteworthy that there is a very high content of organic matter (40-50%) in the interval 700-750 cm (about 13500 years ago).
4. 13100-12400 years ago (640-550 cm of core). The content of silt varies from 60 to 85%, the content of sand varies from 5 to 20%, the content of clay varies from 8 to 15%. The content of organic matter is 20-30%, the content of carbonates greatly increases in comparison with the lower part of the core – from a few percent to 20-30%.
5. 12400-0 years ago (of 550-0 cm of the core). The deposits are represented by peat (the share of organic matter is almost 100%).

In the interval 950-900 cm of the core (15100-14800 years ago) according with the age-depth model) the diatom associations are represented by 21 species, the concentration of valves in sediment is about 20000 valves/cm³. Approximately 85-90% of all valves belong to the benthic oligotrophic and mesotrophic species *Cymboplectura inaequalis*. It prefers slightly alkaline habitats (Kulikovskiy et al., 2016). The next largest species belong to the genus of *Gyrosigma* (*G. attenuatum* and *G. spenceri* species), their content is only 4-5% of all valves.

In the interval 900-860 cm of the core (formed 14800-14500 years ago) content of *C. inaequalis* decreases, it varies from 20 to 70%. The content of other dominant species varies from 2-3 to 12%. These include diatoms that prefer alkaline mesotrophic and eutrophic habitat conditions (*Pseudostaurosira brevistriata*, *Punctastriata lancettula*) and diatoms that can live in water bodies of different trophic status: the alkaphile *Staurosira consrtruens* and the neutrophile *Staurosira venter*.

There are only few valves belong to the species *C. inaequalis*, *G. attenuatum*, *P. brevistriata*, *S. consrtruens* and *S. venter* were found from the sample from a depth of 850 cm. In the interval of 830-770 cm of the core (formed 14400-14100 years ago) 36 diatom species were identified. The dominant species are *P. brevistriata* (its content varies from 8 to 19%), *Punctastriata lancettula* (up to 35%), *Staurosira venter* (about 35%). The content of valves of *Cymboplectura inaequalis* significantly decreases compared to the interval of 950-860 cm – it is less than 1%.

In the interval 770-0 cm of the core (formed during the last 14000 years) no diatoms were found.

4. Discussion

The study of bottom sediments of Sarskoye Swamp allows us to assert that the lake existed in the Sarskaya depression at least from 22500 to 12500

years ago. In the period from 225000 to 14800 years ago sedimentation conditions were relatively stable. The composition of diatom associations indicates the existence of a shallow oligotrophic reservoir with low bioproductivity.

Granulometric composition of bottom sediments at the stage 14800-14300 years ago indicates a possible activation of erosion processes in the watershed. In the period from 1400 to 14100 years ago, according to the dominant species of diatoms, the lake became mesotrophic, its shallow depth preserved.

An increase of the content of carbonates at the stage 14300-13100 years ago may be associated with an increase in the bioproductivity of the lake. The organic matter peak observed in sediments around 13500 years ago may be associated with the the Bølling–Allerød interstadial. At this stage of the development of the lake, diatoms could have disappeared due to the low transparency of the water or the lack of oxygen for photosynthesis.

Content of sand in the bottom sediments formed 13100-12400 years ago indicates significant activation of erosion processes in the watershed. According to the age-depth model, approximately 12400 years ago the lake in Sarskaya basin begun to swamp and the peat accumulation started. It corresponds to the Pleistocene–Holocene boundary.

The absence of peat or lacustrine sediments on the terraced surfaces in the northern part of the basin indicates that the level of the lake in the past never exceeded the present level. That means that the present water level in the basin reaches its maximum in its entire history of development.

5. Conclusions

In the Late Pleistocene, at least from the time of the Last Glacial Maximum to 13100 years ago there was a shallow lake with stable sedimentation conditions in the Sarskaya basin. 13100-12400 years ago erosion processes on the sides of the lake basin became significantly more active. 12400 years ago the surface stabilized and the peat accumulation began. The bottom sediments also show a signal of the the Bølling–Allerød interstadial about 13500 years ago. This confirms the assumption that a global paleoclimatic signal was recorded in the deposits of the Sarskaye Swamp, and this makes their further more detailed study very promising.

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Conflict of interest

The authors declare no conflict of interest.

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Integrating TDR and GPR methods to study the structure of peatland

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ABSTRACT. In this study we compared time-domain reflectometry (TDR) data from boreholes and the results of ground-penetrating radar (GPR) along the cross-sections on a peat deposit. The studied mire located on the Zaonezhye Peninsula (Republic of Karelia, Russia); its structure included layers of peat and bedding lake sediments. To perform the measurements we used GPR with antenna unit 150 MHz and TDR system TDR200 with probe. The mire structure was characterized by a medium basin structure (7 m max depth) and sloping mire topographic. Comparison TDR and GPR data yielded similar dielectric constant values for peat layers. The average mistake in dielectric constant values between TDR and GPR observation was 5 units. The conditions for the formation of interfaces on GPR cross-sections were studied by analyzing dielectric constant change across the peat deposit. We found that the depth positions of the GPR interfaces were quite accurately (± 20 cm) coincides with the intervals of the change of peat type. Our results indicate the difficulty of interpreting GPR cross-sections contained multi-reflectors for subsurface with sub-horizontal structure such as peat deposits or lakes bottom sediments.

Keywords: GPR, TDR, dielectric constant, peat type, decomposition

1. Introduction

Ground penetrating radar (GPR) is widely used to study mire massifs, providing information on their structure and helping identify discontinuities in the peat deposit. There are broad discussion about possibility of using GPR at to determination of peat thickness (e.g. Plado et al., 2011; Parsekian et al., 2012; Parry et al., 2014). However, setting GPR criteria for different types of peat is unsolved. Thus, one of the ways to determine the electrical physical parameters of peat is to combine GPR and time-domain reflectometry (TDR). These techniques can be integrated as they employ similar principles of measuring electromagnetic wave propagation velocity at similar frequencies and deriving the parameters of the medium. In TDR, point measurements are taken through probes in peat samples from boreholes or trial pits, while GPR observations are done from the top surface of peat deposit. The aim of this study was to determine the electrical physical properties of structural elements of a peat deposit.

2. Materials and methods

The GPR method has been applied to study peatland over 40 years (Finkelstein et al., 1979). GPR reliably determines the depth at which the peat deposit is confined by its mineral bed, and can sometimes identify the intermediate layers made up of peat with different characteristics. Wherefore GPR was actively used at the studies of mire stratigraphy and hydrology (Slater and Reeve, 2002; Comas et al., 2004). A particular concern in such studies is the response of the electromagnetic pulses propagation to variations in peat density, moisture and organic matter content (Ryazantsev and Mironov, 2018). Peat deposit parameterization problems can be handled by test boreholes or integrating geophysical techniques (Walter et al., 2016).

TDR is a technique where the velocity of electromagnetic wave propagation in a medium is measured by inserting a special probe into it, and it is actively used to monitor water content in the ground (Jones et al., 2002). This is a tool widely used in the

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studies of peat and peat deposits (Oleszczuk et al., 2004), and can be very effective when combined with GPR. A comparison of the peat electrical parameters with its organic characteristics is provided new criteria for GPR cross-sections interpretation.

The object of this study is the mire situated in the northern part of Zaonezhye Peninsula, Republic of Karelia. The mire covers 3.5 hectares and occupies an elongate depression, oriented NW to SE, filled with peat and lake sediment.

We established a GPR line across the mire with 5 boreholes with peat samples taken each 25 cm. The dielectric constant and conductivity of peat samples were measured by TDR200 with CS635 probe (Campbell Scientific, USA). The botanical composition and rate of decay were described for each sample. GPR survey was done OKO-2 with 150 MHz antenna unit (Logis-Geotech, Russia).

3. Results

The resultant data shows dielectric constant variations across the deposit. The magnitudes decrease with depth – from 65–75 in peat to 30–40 in varved clay. The intensity of GPR interfaces emergence does not always match with the maximum difference in dielectric constant. There is a series of intensive interfaces between peat and gyttja, although the change in dielectric constant between them is in 5–10 units. In regions with high contrast, reflectors can not be illuminated. These are the facts indicate that peat parameters exert a combined effect on the GPR records. A comparison of the boreholes and GPR cross-sections (Fig.) showed that the boundaries between different types of peats were quite accurately determined (within expected error bounds, e.g. ± 20 cm).

The GPR interfaces are matched with the profile of dielectric constant changes. The fact is that, a change of peat type is usually accompanied by a change in rate of peat decay. This effect is sharply appeared in the 2–4 meters depth, where a linear increase in rate of decay leads to an abrupt change in dielectric constant, as result a complex combination of reflectors was formed. The data about peat parameters has enabled an estimation of the reliability of indirect dielectric constant determinations inferred from the hyperbola of the diffracted wave generated by point objects. Fallen tree trunks generate multiple distinct hyperbolas at various depths inside a peat deposit, and dielectric constant can thus be compared. Our results demonstrate a fairly convergence of the direct TDR asses of peat dielectric constant and the indirect GPR asses by means of the hyperbolic fitting.

4. Discussion

The emergence of reflecting boundaries in the study of peat deposits is a complicated question. The variation of peat properties and environmental conditions does not permit for a common set of universal parameters to be made up. A promising approach is to

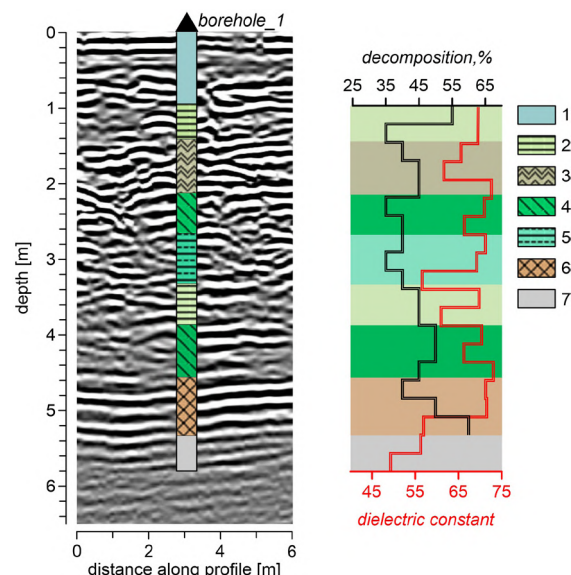


Fig. Comparison GPR and borehole data: 1 – water-saturated peat, 2 – buckbean-sedge peat, 3 – sphagnum peat, 4 – hypnum peat, 5 – sedge peat, 6 – organic gyttja, 7 – clay.

study the interrelated characteristics, i.e. density and degree of decomposition, on which water content is to some extent contingent. The peat decomposition generally results in an increase in electrical conductivity, whereas dielectric constant values remain the same. A question here is the causality of the observed GPR interfaces; whether it is peat density, decomposition or some other factor that produces the greatest effect on the electrical properties, and what GPR patterns do they have. More complex data need to be involved to solve this problem.

5. Conclusions

The reported studies prove the combined application of TDR and GPR is effective. A detailed survey of the peat deposit demonstrated a differential change of electrical physical properties along a gradient. The analysis of data from boreholes helped reveal the source of reflector emergence inside the deposit. Even minor variations in dielectric constant were found to be able to induce the emergence of reflecting boundaries. The patterns identified in the distribution of peat electrical physical properties enabled an interpretation of the GPR profiles, which would have otherwise been impossible.

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Conflict of interest

The authors declare no conflict of interest.

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Limnogenesis of large lakes in the North-West of the Russian Plain

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ABSTRACT. The issues of the formation of the largest lakes in Europe - Ladoga and Onega are considered in the article. The main aim was to identify features of the basins development from their origin to modern condition. The newest geological and geophysical data obtained in 2014-2021 was used to achieve the goal. Both depressions, in which modern lake basins are located, were formed in the Late Proterozoic. In the Late Quaternary, the glacier significantly modeled the pre-Quaternary relief. Glacial tongues significantly expanded the negative forms of the pre-glacial relief. At the same time, the glacier also formed positive landforms, such as moraines and esker ridges. Such ridges intersect the Lake Ladoga center and mark the position of the Neva stage. Structural features of the supraglacial section are considered in detail. It is shown that in both lakes the structure of the upglacial section is approximately the same and is associated with the gradual retreat of the glacier from the lake basins. Thus, it is shown that, despite the similarity of the main stages of paleogeographic development, each lake basin was characterized by its own features and their development itself occurred asynchronously.

Keywords: Quaternary, Lake Ladoga, Lake Onega, paleogeography, glacial lake, till, seismoacoustic profiling, lacustrine sediments, varve, pollen analysis

1. Introduction

The history of the formation of inland water basins along the eastern periphery of the Baltic Crystalline Shield is one of the key problems of the Quaternary geology at the North-West of the Russian Federation. These are the Baltic and the White Seas and Lake Ladoga and Lake Onega lakes. Comprehensive geological and geophysical work in the waters of the lake basins began much later than in the seas. However, in the last 8 years, multichannel high-resolution seismoacoustic profiling has been carried out on both lakes (Aleshin et al., 2019). Geological sampling in the same years was carried out on Lake Onega. As a result, a new version of the map of Quaternary deposits of Lake Onega was presented (Beljaev et al., 2021). A

special paleogeographic zoning was carried out, which made it possible to visualize the development of Lake Onega in the Late Pleistocene-Holocene (Subetto et al., 2019). In this report, we want to focus on the history of the formation of both largest lakes in Northern Europe, which is basing on the results of complex geological and geophysical work in 2014-2021.

2. Materials and methods

Field work on the study of Quaternary deposits of Ladoga and Onega lakes included:

- multi-channel high-resolution seismo-acoustic profiling with various sources of signal excitation (sparker, bummer);

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- geological sampling using a gravity corer 3 m long and weighing up to 500 kg, which made it possible to obtain cores up to 2.5 m long.

Laboratory work was carried out in St. Petersburg and Moscow and included: grain size and pollen analysis and core tomography.

3. Results

The formation of depressions along the Eastern periphery of the Baltic Crystalline Shield, where the Ladoga and Onega lakes subsequently formed, occurred in the Late Proterozoic as a result of destruction processes in the pre-platform period of the Russian Platform development. However, it happened in different ways. Lake Ladoga largely inherited the narrow aulacogen trough, which, in turn, inherited the position of the Paleoproterozoic collisional belts (Baluev et al., 2012). Lake Onega basin is framed by the Late Proterozoic Onega structure. Its structural plan predetermined the specific orography of the north of the lake. In the Quaternary, all negative forms of the pre-Quaternary relief were modeled by the glacier. These tectonic depressions became pathways for the Late Weichselian ice tongues (Subetto et al., 2020).

Only the deposits of the last glacial-sedimentary cycle were found in Lake Ladoga and Onega: Late Valdai moraine, limno-glacial deposits, and modern lacustrine deposits. In Lake Ladoga, according to the drilling data of a joint Russian-German expedition, the presence of the Mikulino-Early Weichselian deposits was established (Lebas et al., 2021). However, the geophysical data in this area do not allow to agree with this opinion, since they indicate a deeper occurrence of the roof of the moraine of the last glaciation. The bottom morphology of both lakes is different. In the northern Lake Ladoga there is a deep-water basin, which is separated by the Valaam sill from the flat plain of the central and southern parts of the lake. At the same time, in the center of this plain, the lake is crossed by a complex of ridges of glacial and fluvioglacial origin. In Lake Onega, the northern part is occupied by fiard bays. In the easternmost of them (Povenets Bay), esker ridges are established. It is the marginal form of glaciation, which we compare with the Neva stage of the Valdai glaciation. These ridges are well distinguished by seismoacoustic profiling data. The SP-0002 borehole in the Petrozavodsk Bay exposed dense sandy-clay silt (silty miktites) of gray and dark gray color with a large number of fragments of crystalline rocks. They form the so-called “cupcake-like” texture (Rybalko et al., 2020).

The principal question is the time of the onset of deglaciation in both basins. The most complete data have now been obtained for the Onega basin. The beginning of the formation of the periglacial lake due to the glacier melting began around 14500 years ago (Subetto et al., 2019). The release of the southern and the central parts of the lake from the ice cover occurred 14000 years ago. The melting of the glacier due to the ongoing climate warming has led to a shift

of its margin to the north. The edge of the glacier about 13.3 thousand years ago located along the western and northern borders of the modern Onega Basin. It was the time of the periglacial lake maximum development (Subetto et al., 2019). In Lake Ladoga, the only date of the beginning of the periglacial lake formation is the data of the Russian-German expedition in 2013. According to these data, the accumulation of varves began 13.9 ka BP (Lebas et al., 2021). This is 600 years later than in Lake Onega.

The section of supraglacial deposits in both lakes is nearly similar that indicates a certain cyclic recurrence of paleogeographic events in the postglacial period. In Lake Onega, the most complete section of limnoglacial clays was uncovered by a borehole in Petrozavodsk Bay (Subetto et al., 2020). Here, it was represented by a pattern of thick-layered interbedding of sandy clays and silts overlain by a strata of varves and, above, microlayered clays (Rybalko et al., 2020). The three-member structure of the glacial-lake clay sequence was also recorded in Lake Ladoga (Rybalko et al., 2016). In the upper parts of section in both lakes, there is a pattern of gray (gray with a greenish tinge) dense siltyclays, which is overlain by a strata of greenish-brown lacustrine muds. However, according to palynological analysis, the age of the identified lithological layers is different. In Lake Ladoga, the accumulation of limnoglacial clays ended in the Younger Dryas. In Lake Onega, the accumulation of monotonous gray muds had already begun at that time, i.e., lacustrine sedimentation began already in the Late Pleistocene.

4. Discussion and conclusions

Thus, the conducted investigations have shown that in the Late Quaternary the environment in Ladoga and Onega regions was developing according to the union scenario. At first near-glacial lakes emerged. Their culmination happened due to water-level regression, accompanied by the fine clayey sediments accumulation. Afterwards, lacustrine sedimentogenesis took a place featured by the accumulation of muds with an increased amount of organic matter. At the same time, the formation of Lake Onega occurred with an active inflow of water from the south Lake Ladoga, on contrast, was located at the northern and the central parts of its basin after periglacial lake drainage through the Swedish straits at the beginning of the Holocene. The lake acquired its modern shape due to the Ladoga transgression

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Conflict of interest

The authors declare no conflict of interest.

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Late-Glacial and Early Holocene history of Lake Khotavets (Mologa-Sheksna Lowland, NW Russia): a geodiversity conservation case study

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ABSTRACT. Evolution and regional climate changes during the Late Glacial/Holocene transition were studied using organic and inorganic geochemical proxies and pollen data from Lake Khotavets (NW Russia). Palaeoclimatic and palaeosedimentation sequence was described for the time slices 13.5 – 12.9, 12.9 – 11.8 and 11.8 – 11.1 cal. ka BP, attributed to the Allerød, Younger Dryas and Preboreal, respectively. Rapid organic accumulation, decrease of minerogenic input and woods expansion ~11.8 cal. ka BP were associated with the Holocene warming. The presented reconstruction determines scientific justification for specific geodiversity conservation.

Keywords: palaeolimnology, Early Holocene, Late Glacial, pollen, geochemical proxies, sedimentation, geodiversity

1. Introduction

Chronology of the climatic changes in the central Mologa-Sheksna Lowland (MSL) during the Last Glacial Termination and the Holocene onset is still poorly investigated. First reliably dated materials for the MSL Late Glacial climate dynamics, supported with geochemical evidence, were obtained for Lake Beloye of the northern MSL, where detailed palaeosedimentation cyclicity, starting from Bölling, was studied by Sadokov et al. (2022).

Bogs and mires span over 80% of the Darwin Nature Reserve territory, and more than 30 minor lakes are located on the boggy plains. These landscapes are essential for the biodiversity and geoheritage conservation in the central MSL, due to their biosphere effect for the wildlife and the local hydroclimate, and as well due to high scientific value (Crofts et al., 2020).

A multiproxy approach (geochemistry, AMS dating, palynology) enabled to disclose a series of palaeoclimatic and palaeohydrological changes, recorded in the lacustrine sediments.

2. Materials and methods

Lake Khotavets (N 58.568°, E 37.603°) is located within the Mologa river basin in the Vologda

region. The lake is situated at 102.4 m above sea level (a.s.l.), covers an area of 1.24 km² and is an average 2 m depth.

The sediment cores were extracted in 2018 by Russian corer (diameter 5 cm, chamber length 1 m). Total length of the sediment sequence was 425 cm, which corresponds to the depth range 210 - 635 cm from the ice surface. X-ray fluorescence scanning was conducted in the University of Cologne (Germany) on the ITRAX XRF Core Scanner with Cr-anode tube, 30 kV, 55 mA, dwell time 5 sec and step size 2 mm. Upper 109 cm of the core was not used for measurements due to the laboratory error, so the measured core length was 316 cm. Total organic carbon (TOC) and total carbon (TC) content were measured on Dimatoc 2000 and Vario MICRO cube respectively, after freeze-drying and grounding. Total inorganic carbon (TIC) amount was calculated as a difference between TOC and TC. Pollen analysis was performed in the Institute of Limnology RAS (Russia). Technical treatment of samples for pollen analysis followed a standard method (Grichuk, 1940).

Age values were determined using accelerator mass spectrometry (AMS) at the Laboratory of the Radiocarbon Dating and Electronic Microscopy (Institute of Geography, Moscow). The obtained ¹⁴C ages were calibrated using IntCal20 calibration curve (Reimer et al., 2020). An age-depth model was generated in R

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software ('rbacon' package), with the use of Bayesian inference.

3. Results and discussion

Three zones were outlined in the studied sequence according to the XRF and carbon measurements (Fig.). Zone I (635–588 cm, 13.5 – 12.9 cal. ka BP) embraces deposits of the interstadial environment, which is most prominently expressed during the sub-zone Ia in the decrease of minerogenic input of K and Ti and slightly enhanced TOC values (Davies et al., 2015) (Fig.). Allerød age of Zone I was confirmed by pollen and age-modelling, with relatively warm and wet climate reconstructed by the abundance of wood pollen (Sapelko and Sadokov, 2022).

The onset of cold and dry climate is related to the Younger Dryas, evidenced by the decline of the trees pollen and dominance of herbs pollen (*Artemisia*, *Poaceae*, *Chenopodiaceae*, *Cyperaceae*, *Dryas octopetala*, *Ephedra*) and by enhanced accumulation of K and Ti, presumably induced by the higher weathering rate (Davies et al., 2015) (Zone II (587–530 cm, 12.9 – 11.8 cal. ka BP), Fig.). The lake level started to fall stepwise from the sub-zone IIb, as documented by the Mn/Fe and distribution (Davies et al., 2015) (Fig.).

The Holocene onset is recorded by the most of the applied proxies. A shift to organic sedimentation is marked by lithological changes, rapid TOC growth and lithogenic elements (Ti, K) decrease. Elevated lacustrine bioproductivity is proposed for the sub-zone IIIa (529–507 cm, 11.8 – 11.2 cal. ka BP) (Fig.), confirmed by the sharp peaks of Ca and TIC content, which are probably related to the excessive carbonates formation in the water column (Kelts and Hsü, 1978). Expansion of pine and birch woods towards the Lake Khotavets basin over the grassy xerophyte plains indicates warmer and wetter climate conditions of Preboreal. Enhanced

oxygenation of the bottom water (high Mn/Fe values) (Davies et al., 2015) is interpreted as a proxy of the ultimate palaeolake drainage ~10.7 cal. ka BP.

4. Conclusions

New data on the Lake Khotavets sediments chemical and pollen composition provide basis for the palaeoclimate reconstruction for the Late Glacial and Early Holocene in the central MSL. The outlined geochemical and pollen units correspond well to the accepted Late Glacial climatostratigraphy of the Northern Europe. Allerød – Younger Dryas – Preboreal transition is documented in the vegetation changes derived from the pollen data. Weathering rate was the highest 12.9 – 11.8 cal. ka BP, altered by the rapid organic sedimentation and endogenic carbonates accumulation from ~11.8 cal. ka BP. The palaeolake level had dropped successively ~12.3, ~11.8 and ~10.7 cal. ka BP.

Palaeolimnological research of the Lake Khotavets basin became the first of a kind to investigate the Late Glacial evolution of the Darwin Nature Reserve natural systems. A series of the disclosed short-term palaeoenvironmental shifts recorded in the lacustrine sediments creates an insight into the origins of the local relief, hydrographical network and landscape structure, thus raising the scientific value of the geoheritage significantly.

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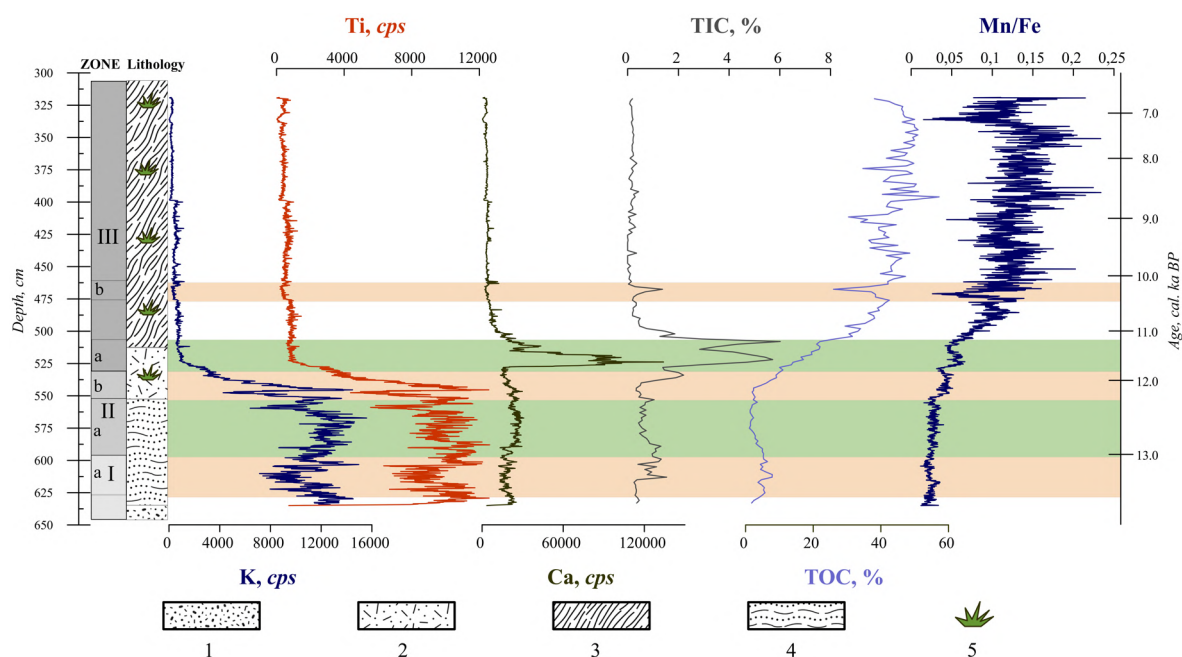


Fig. Lithology and vertical distribution of K, Ti, Ca, ratio Mn/Fe, TOC and TIC in Lake Khotavets sediments. Intensity of x-ray reflection is given in counts per second (cps). Age axis is built according to the age-depth modeling in 'rbacon'. 1 –layered sandy silt, 2 – silt with organic matter, 3 – organic muds, 4 – rhythmically layered silt with organic matter, 5 – plant fossils

Darwin State Nature Biosphere reserve», 2019, 2020). The authors are grateful to Martin Melles and Nicole Mantke for the laboratory studies conducted in the University of Cologne in frames of the joint academic grant scholarship program “Dmitrii Mendeleev” of St. Petersburg State University, University of Cologne and German Academic Exchange Service (DAAD) (2018).

Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Vegetation dynamics in the Rostov lowland (Yaroslavl oblast) during the Late Glacial and Holocene based on a new pollen data

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ABSTRACT. Our reconstructions of vegetation changes are based on the results of pollen analysis that was carried out for the sedimentary sequence located on the lacustrine-alluvial terrace west of Lake Nero. To clarify our conclusions, six ^{14}C dates were obtained and an age-depth model based on these dates was constructed. It is established that open spruce-birch forests were widespread during the Allerød and Younger Dryas. Since the Preboreal stage of the Holocene, a peat bog began to form surrounded by pine and birch forests with spruce. The Boreal stage was marked by an increased role of broad-leaved trees in the forests. During the Atlantic period, climatic conditions became warmer and spruce-pine forests with thermophilous deciduous trees started to grow. The vegetation cover of the Late Holocene (SB-SA periods) was dominated by spruce forests with pine and birch.

Keywords: pollen, spores, reconstruction of paleoenvironment, peat bog, Lake Nero

1. Introduction

Lake Nero, located in the southern part of the Rostov lowland, has been one of the main paleogeographic objects of study for many years in the Upper Volga region. The lake has a complex Late Glacial and Holocene history due to the changes in its level and the fluvial network transformation. Palynological investigations have already been conducted in this area, but the most of them were poorly provided with absolute dates (Gunova, 1972; Aleshinskaya and Gunova, 1975). Moreover, according to recent studies (Wohlfarth et al., 2006), a hiatus in sedimentation is recorded in the bottom sediments of Lake Nero during the Younger Dryas and the Early Holocene.

For paleogeographic reconstructions, we have chosen a section that is situated on a lacustrine-alluvial terrace west of Lake Nero. This section characterizes the history of the fluvial valley, sedimentation in which continued during the Late Glacial and Holocene. The study of this sedimentary sequence will fill in some gaps and expand the understanding of the vegetation history in the study area.

2. Materials and methods

The main object of this study – the K7C core – is located on the lacustrine-alluvial terrace at an altitude of 11 m above the Lake Nero level (N 57.191579; E 39.310386). The sequence is 2 m long. Core sediments

were studied by pollen analysis with sample interval 5-10 cm (37 samples in total). Samples were processed using the method of V.P. Grichuk (Grichuk and Zaklinskaya, 1948) with the acetolysis procedure at the final stage (Mazei and Novenko, 2021). Samples were subsequently examined under the microscope with 400x magnification. The pollen percentage diagram and the pollen concentration diagram were constructed with the TiliaGraph software (Grimm, 2004). On the pollen percentage diagram, the percentage values of all taxa were calculated in the ratio to AP+NAP sum. A cluster analysis was used to identify local pollen zones (hereinafter LPZ).

Radiocarbon dates for 6 samples were obtained in the Laboratory of Nuclear Geophysics and Radioecology (Nature Research Centre, Vilnius, Lithuania), and an age-depth model based on these dates was constructed.

3. Results

The sediment sequence of the K7C core consists of several layers. The basal loam unit (2.0-1.83 m) and peaty loam unit (1.83-1.45 m) pass into peat unit (1.45-0.38 m) with two interbeds of 5-cm-thick organic carbonate silt. The upper part of the core is composed of peaty loam (0.38-0 m).

The pollen diagram commences with the *Betula*-dominated LPZ 1 (2.0-1.63 m) with low *Picea* and *Pinus* s/g *Diploxylon*. The pollen grains of shrubs such as *Betula* sect. *Fruticosae*, *B.* sect. *Nanae* and *Salix* are found, and

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their concentrations are high (*B. sect. Fruticosae* – up to 5000 grains per cm³, *B. sect. Nanae* – up to 500, *Salix* – up to 7000). This pollen zone is also characterized by high NAP and *Artemisia* pollen values. Two subzones can be identified in the LPZ 1: the LPZ 1A (2.0-1.87 m) and the LPZ 1B (1.87-1.63 m). The LPZ 1A has the lowest total pollen concentration of all pollen zones (5000-6000 grains per cm³); it is also distinguished by higher *Picea* and lower *Artemisia* and *Chenopodiaceae* compared to the LPZ 1B.

In the following LPZ 2 (1.63-1.18 m), NAP dominates together with *Poaceae*. According to the results of the botanical composition analysis of peat, which was carried out by Stoykina N.V. in the Laboratory of Wetland Ecosystems (Institute of Biology, Karelian Research Centre RAS), numerous macrofossils of *Phragmites* are found at these levels. In pollen assemblages, AP values constitutes 5-43% of the total pollen and spore sum. *Betula sect. Albae* still predominates, but it declines toward to the upper part of the LPZ 2, as does *Picea*. *Pinus s/g Diploxylon*, on the contrary, increases in the upper part. Pollen of broad-leaved trees is insignificant. It is worth noting the presence of *Ephedra* and *Thalictrum* pollen in the NAP group.

The next LPZ 3 (1.18-0.57 m) is characterised by high content of *Pinus s/g Diploxylon* and *B. sect. Albae* together with *Cyperaceae*. At these levels, great amount of *Carex* macrofossils occurs (according to the results of the botanical composition analysis of peat). Percentages of AP and NAP are approximately equal. Spores are abundant, especially *Polypodiaceae*. The LPZ 3 should be divided into two subzones. The lower subzone LPZ 3A (1.18-0.87 m) is characterized by the higher content of *Artemisia*, while the upper subzone LPZ 3B (0.87-0.57 m) shows a wide variety of thermophilous deciduous tree pollen (*Quercus*, *Ulmus*, *Corylus*, *Tilia*, *Lonicera*, *Sambucus*).

The following LPZ 4 is identified at 0.57-0.22 m depth. An increase of AP values takes place (43-83% of the total pollen and spore sum). *Picea* starts to rise and prevails together with *Pinus s/g Diploxylon*. *Alnus* pollen values increase. In this pollen zone, there is an abundance of deciduous tree pollen, namely *Tilia*, *Quercus*, *Corylus* and *Ulmus*. Pollen concentrations of these taxa are high (*Quercus* – up to 3000 grains per cm³, *Tilia* – up to 9000, *Corylus* – up to 6000, *Ulmus* – up to 3000). The content of NAP decreases.

The uppermost LPZ 5 (0.22-0 m) is distinguished by less abundance of thermophilous deciduous tree pollen and lower total pollen concentration compared to the LPZ 4.

4. Discussion

According to the age-depth model and pollen spectra, it can be assumed that the sediment sequence of the K7C core formed from the Allerød to the Late Holocene (SB-SA periods).

The basal alluvial-deluvial loam unit represents a sediment bed that was deposited during the Allerød stage

(LPZ 1A). A high terrigenous content and low pollen concentrations indicate a rapid rate of sedimentation. Then, during the Younger Dryas period, sedimentation rates slowed down and peaty loam accumulated (LPZ 1B). Open spruce-birch forests dominated the Allerød and Younger Dryas periods. Open spaces were occupied mainly by xerophytic formations and meadow herbs. During the Preboreal stage (11.75-10.75 cal. ka BP), a peat bog existed above the section. It began to form as a lowland reed wetland (LPZ 2) and subsequently transformed into a sedge wetland (LPZ 3A). Pine and birch forests with spruce grew in the vicinity of the peat bog. Due to ongoing warming (LPZ 3B), pine-birch forests with broad-leaved trees started to grow (the Boreal stage; 10.75-8.2 cal. ka BP). The content of broad-leaved trees gradually increased in the woods. During the Atlantic period (LPZ 4; 8.2-5.3 cal. ka BP), forests became denser. Climatic conditions got even warmer. It caused the widespread of spruce-pine forests with thermophilous deciduous trees. Further (LPZ 5) there were changes to cooling. The Late Holocene (Subboreal-Subatlantic periods) is recorded only in the upper 22 cm of the peaty loam unit in the K7C. The vegetation cover was dominated by spruce forests with pine and birch. The results of other palynological investigations (Wohlfarth et al., 2006) also confirm the predominance of spruce-pine-birch forests during the Late Holocene in the surroundings of Lake Nero.

5. Conclusions

The K7C section is a valuable paleogeographic archive that was characterized by a continuous deposition of sedimentation during the Late glacial and the Holocene. It allowed us to reconstruct vegetation dynamics since the Allerød stage in the vicinity of Lake Nero. The most significant is that almost half of this sequence (0.8 m) is the peat horizon that accumulated during the Preboreal stage of the Holocene. Pollen assemblages of this time span were poorly studied before in this region.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Correlating paleolimnological results with radiocarbon dating of Lake Ladoga sediment sequences

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ABSTRACT. Despite of a long period study of the sediments sequences of Lake Ladoga there are currently only two cores with a series of radiocarbon dates. Now the radiocarbon dates for one more core have been received. The results of new multi-proxy studies have been obtained. The new series of radiocarbon dates allows the obtained data to be correlated with other dated cores. Our studies show different sedimentation conditions in different parts of Lake Ladoga in the same time periods. In this regard, for a correct reconstruction of the history of Lake Ladoga, it is necessary to continue multi-proxy studying of the cores with a series of radiocarbon dates.

Keywords: lake sediments, Late Pleistocene, Holocene, Ladoga, AMS radiocarbon data

1. Introduction

Lake Ladoga is the largest lake in Europe. The study of Lake Ladoga sediments began with the Ladoga complex expedition of the Institute of Limnology of the Academy of Sciences of the USSR led by N. I. Semenovich in 1959 (Semenovich, 1966). The first conclusions on the features of lake sedimentation were made based on the pollen and diatom data (Abramova and Davydova, 1966; Abramova et al., 1967). Age estimations were determined according to pollen analysis. All further numerous results of paleolimnological studies were also mainly dated by the pollen method (Sapelko et al., 2021). Despite a long period of study of the sediments sequences in Lake Ladoga, until recently only a few occasional radiocarbon dates were available. The reason for this is a very low organic content in the Ladoga sediments insufficient for routinely applied bulk sediment dating. A radiocarbon age of 6660 ± 240 yr BP (LU-2817) was obtained from the sediment section in the north-eastern part of Lake Ladoga at a depth of 121m ($61^{\circ}33'25''$ N, $31^{\circ}20'7''$ E). The Atlantic age of the sediments was confirming by pollen analysis (Arslanov et al., 1996). At the sediment core near the Valaam Island ($61^{\circ}23'0''$ N, $30^{\circ}55'8''$ E) the age of the 185 cm-thick sediments retrieved at a depth of 3 m was 7310 ± 1230 yr BP (LU-3042), which is also confirmed by the results of pollen analysis (Subetto et al., 1998). A wood fragment accidentally found in the varved clay

retrieved from the south-eastern part of Lake Ladoga ($60^{\circ}42'75''$ N, $32^{\circ}34'75''$ E) was dated to 15620 ± 50 (LU-2815; Arslanov et al., 1996). In 2013, in the framework of the Russian-German project PLOT, a deep water drilling was performed (Andreev et al., 2019). A series of radiocarbon (AMS) and pollen stratigraphy data a 20-m long sediment sequence at a depth of 111 m in the northwestern part of the Lake Ladoga, near the Konevets Island ($60^{\circ}59'02.2''$ N, $30^{\circ}41'027.1''$ E, Co1309, Fig.) was received (Savelieva et al., 2019).

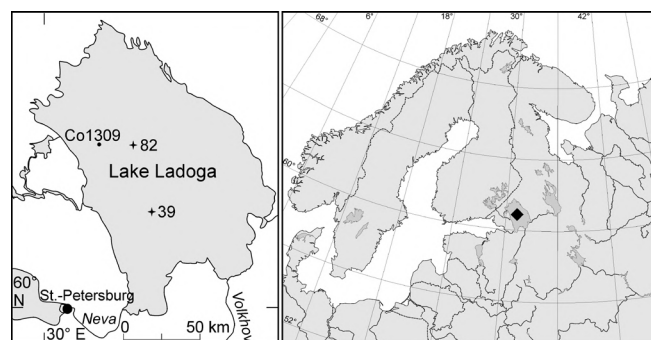


Fig. Location map and sites with a series of radiocarbon dates.

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2. Materials and methods

In summer 2016 and 2020, sediment cores were retrieved in the central and southwestern open parts of Lake Ladoga (Fig.) at the station 82 (60° 59.104' N; 31° 08.982' E, depth 68 m) and the station 39 (60°33, 919'N; 31°23, 57'E, depth 54 m) (numeration according to the network of the stations for regular observations of the Institute of Limnology, RAS, (Ladoga, 2013). The analyses included lithology, loss-on-ignition (LOI), phosphorus, metals, grain-size distributions, sediment density, pollen, diatoms and radiocarbon AMS dating. The radiocarbon dates were obtained by accelerator mass spectrometry (AMS) at the Laboratory of radiocarbon dating and electronic microscopy, Institute of geography RAS (Moscow, Russia).

3. Results and discussion

Now we received the new results of the multi-proxy study of the Lake Ladoga sediment sequence at southwestern parts of Lake Ladoga (station 39). We can compare results of all methods to the data for other dated sediment cores in the central (Sapelko et al., 2019) and northwestern parts of Lake Ladoga (Savelieva et al., 2019). For the first time for Lake Ladoga, changes in phosphorus during the Holocene dated by the radiocarbon method were obtained, for cores of station 39 and Co1309 (Gromig et al., 2019).

Lake Ladoga was characterized with low ecosystem productivity with low diatom abundance, low diatom species diversity and mineral sedimentation (LOI not exceeding 3-5%) in the large and deep-water basin during the Late Glacial-Early Holocene. The content of clay fractions was highest. The concentrations of metals in the studied cores were differ, which may indicate the local specifics of sedimentation in the Ladoga basin. The phosphorus content in sediments does not exceed 1 mg g⁻¹. The cool and dry climate is indicated by periglacial landscapes. The cold climate of the Late Glacial period was recorded in all three dated cores. Radiocarbon dates (AMS) of 12718 cal. ka BP fixed the Late Glacial period in core 39. Radiocarbon dates (AMS) of 14124±69 cal. ka BP and 12834±68 cal. ka BP fixed the Late Glacial period in core Co1309 (Savelieva et al., 2019).

For the Holocene period a series of radiocarbon dates have been obtained to confirm the pollen stratigraphy and to date changes in sedimentation conditions in Lake Ladoga. Several radiocarbon dates in the upper parts of the cores of the open part of the Lake Ladoga showed the lowest rate of sedimentation in the modern period. In the northern part of open Ladoga, about 27–35 cm of sediments accumulated over a period of about 2500–2860 years (Sapelko et al., 2019; Savelieva et al., 2019). At the same time, no more than 20 cm accumulated during 1863–1737; in the period of ca. 1338–1292 - no more than 10 cm, and in the period of 1320–1289 - no more than 5 cm (Sapelko et al., 2019). In the southern part of open Ladoga (station 39), about 30 cm of sediments were formed in 3300 years and no more than 10 cm of sediments were formed in 2585 years.

4. Conclusions

Our studies show different sedimentation conditions in different parts of Lake Ladoga in the same time periods. It is impossible to obtain a complete picture of the Late Glacial – Post Glacial history of Lake Ladoga from a single sediment sequence selected from one point. For a correct reconstruction of the history of Ladoga, it is necessary to continue a multi-proxy study of cores from different parts of the lake with radiocarbon dating.

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Conflict of interest

The authors declare no conflict of interest.

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Late Pleistocene Lakes of the Manych Depression (Caspian and Azov-Black Sea basins, Russia)

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ABSTRACT. The first geochronological data have been obtained for the lacustrine deposits of the Manych Depression, discovered by a borehole. It was found that two horizons (burtass and gudilovsky) of sedimentation were distinguished in the lacustrine deposits separated by an erosion gap. The age of the Burtass Lake deposits is estimated at 78-100 ka years ago (MIS 5), Gudilovsky Lake — 25-64 ka years ago (MIS 3).

Keywords: palaeogeography, Manych Depression, malacofaunistic analysis, OSL dating, geochronology, biostratigraphy

1. Introduction

The Manych Depression is a vast, weakly dissected low lying plain, stretching from the northwest from the mouth of the Don River to the southeast to the Northern Caspian for more than 500 km.

Based on the analysis of lake sediments filling the valleys of the Western and Eastern Manych Rivers in the Late Pleistocene history of the depression a huge lake was reconstructed, which formed after the closure of the Hyrcanian Strait and was named Burtass.

A large number of researchers have been studying the burtass (gudilovsky) deposits (Goretsky, 1958; Popov, 1983; Svitoch et al., 2011; Badukova, 2015, etc.), however, there is still no consensus on the

duration of the existence of the lake, the factors of its formation, how the time of its existence correlates with the states of the Caspian and Azov-Black Sea basins. Many questions have not yet been answered, largely due to the lack of geochronological data.

Here we present the first dates obtained for lacustrine deposits of the Manych Depression using the OSL method.

2. Materials and methods

Borehole MN-1 (N46°26'52,7 E42°41'19,6) with depth 42,0 m, was drilled near Gruzskoe Lake (Fig. 1) at a height of 19.2 m.

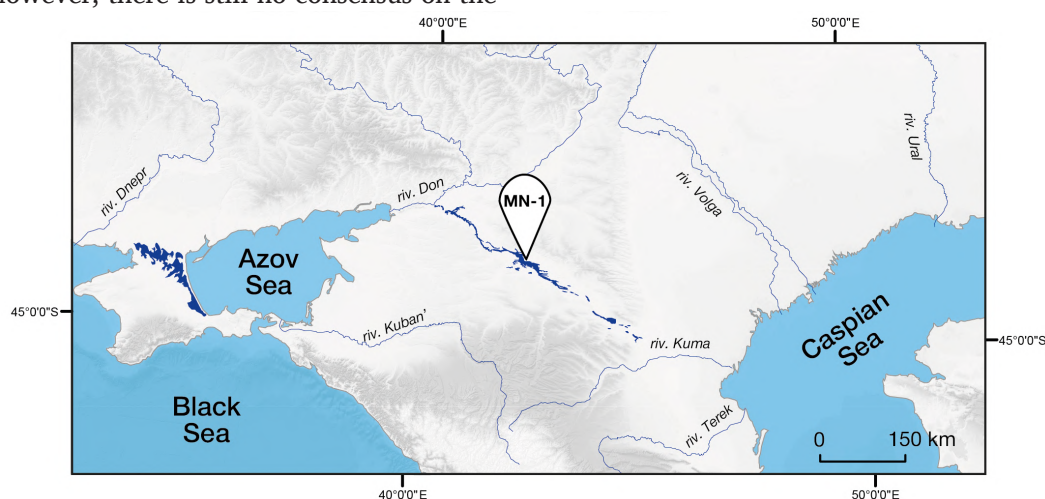


Fig.1. Location of the MN-1 drilling site in the Manych Depression.

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The sediments of the borehole were studied by the malacofaunistic method in order to provide a biostratigraphic substantiation of the highlighted sediments. Geochronological data were obtained using the OSL dating method.

3. Results

In the MN-1 borehole core (Fig. 2), the following deposits are exposed from top to bottom: (1) modern soil 1.2 m thick, transition to the underlying sequence is gradual; (2) light brown loam in the range of 1.2–15.0 m from light at the top to heavy at the base with inclusions of gypsum and silt interlayers, the boundary with the underlying layer is clear; (3) bluish-dark gray clay at a depth of 15.0–18.0 m with inclusions rare crystals of gypsum, interlayers with mollusc shells, manganese stains, and ferruginous spots; accumulation of shell detritus is observed in the roof; silt interbeds, gradual transition to the underlying sequence; (4) dark gray clay at a depth of 18.0–20.4 m with inclusions of carbonates and ferrugination spots, gradual transition to the underlying sequence; (5) bluish-gray light to medium silty loam at a depth of 20.4–27.6 m with inclusions of ferruginous and manganese spots, interlayers of silt occur, in the interval of 25.8–26.0 m a darker gray interlayer is observed, enriched in detritus, small fragments of thin mollusk shells, at the bottom of the layer there is a sandy interlayer with inclusions of mollusk shells, the boundary with the underlying layer is clear.

Malacofaunal analysis of the core showed that at a depth of 27.6–25.8 m there are shells of freshwater and slightly brackish mollusks (*Dreissena polymorpha*, *Unio* sp., *Viviparus* sp., *Valvata* sp.), which indicates the existence of a calm freshwater basin.

Three samples were taken for geochronological analysis by the OSL dating method. During the study, three dating protocols were used (Kurbanov et al., 2019): for quartz (OSL) and for feldspar (IR_{50} and $pIRIR_{290}$). The samples showed the presence of a fast component in the samples of quartz (OSL), in connection with this, the absolute age was obtained from quartz.

The accumulation of the Burtass lake deposits began after the closure of the Hyrcanian Strait about 100 ka years ago (Kurbanov et al., 2018), and ended no earlier than 78 ka years ago. The overlying light brown loam accumulated in the interval 25–64 ka years ago.

4. Discussion and conclusions

In the central part of the Manych Depression after the closure of the Hyrcanian Strait sediments of the freshwater Lake Burtass began to accumulate. The results of OSL dating showed that the lake existed here up to 78 ka years ago, i.e. before MIS-4. It is possible that Lake Burtass was a relic of the Hyrcanian Strait, which quickly desalinated under the influence of local watercourses. The climate still remained interstadial at the end of MIS-5 (Kurbanov et al., 2018) and, apparently, the lake had a positive water balance,

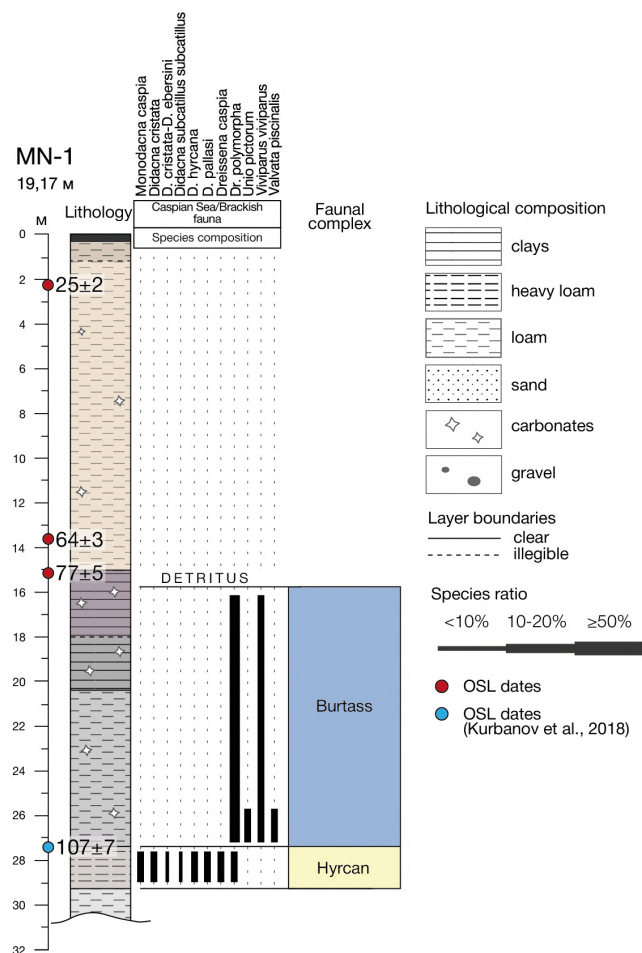


Fig. 2. Lithology, biostratigraphy and geochronology of deposits from the MN-1 borehole.

which led to the existence of a full-flowing freshwater Lake Burtass within the Manych Depression for MIS-5.

As a result of climate warming during MIS-3, a river flow into the Manych Depression was apparently increased. According to the high concentration of gypsum in the composition of the sediments, shallow water body that dried up from time to time — Lake Gudilovsky — reappeared on the site of the once existing Lake Burtass. The period of accumulation of sediments in these water bodies according to the results of OSL dating is estimated at 25–64 ka years ago.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.

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Reconstruction of Holocene environmental conditions based on the complex studies of Lake Shnitkino sediments (Tver Region, Russia)

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ABSTRACT. The presented study aims to investigate the paleoenvironmental conditions of Lake Shnitkino in Tver Region (northwestern European Russia). Two sediment cores from the lake bottom were obtained and analyzed using lithological and paleobotanic methods. The Holocene landscape and climatic characteristics of the lake basin are reconstructed. Four stages of lake evolution were inferred: 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, and 4) Recent time.

Keywords: limnology, lithostratigraphy, pollen analysis, bioindicators, Late Glacial/Holocene transition

1. Introduction

This work aims to reconstruct the Holocene limnologic features of Lake Shnitkino. Landscape dynamics and climatic conditions influenced the reservoir conditions and its catchment area on a regional scale. Locally the lake is strongly connected with the fluvial system. Lake Shnitkino is located in northwestern European Russia in the upper reaches of the Zapadnaya Dvina (Daugava) River. The Toropa River – a right tributary of Daugava – flows through Lake Shnitkino from the north to the south. The paleoenvironmental changes of the studied area were investigated during geoarchaeological research near the medieval site Shnitkino.

2. Materials and methods

Key site and regional settings. Lake Shnitkino is 4 km long and up to 0.8 km in width. The maximum depth of the lake is 2m. The lake has many small tributaries and the main tributary is the Toropa River. The lake is acting as a local basis for the Toropa River, causing the accumulation within its inflow into the lake. The surroundings of the river-lake system are the Late Pleistocene hilly plains with kames, and swampy meltwater depressions.

The fieldwork was performed in 2020 and analytical work during 2020-2022. The fieldwork included lake-bottom sediment coring using an Eijkelkamp manual auger. Sediment core profiling with a lithostratigraphic description of eight cores was

made and representative cores 20770 and 20769 were sampled for lithological (grain size, loss on ignition, and magnetic susceptibility analyses), pollen analysis, and the study of the biological composition of sediments. The core 20770 is 8.5m long. It is located in the central part of the northern Shnitkino lake basin and is composed fully of massive or laminated lacustrine sediments. The core 2069 is 5m long. It is located closer to the shoreline and composed of lacustrine and alluvial deposits.

The grain size analysis (GS) was carried out with laser diffractometry using a Malvern Mastersizer 3000 instrument. The particle size distribution was calculated based on the Fraunhofer diffraction model (Konert and Vandenberghe, 1997). Concentrations of organic matter and CO₂ from carbonates were determined by loss on ignition (LOI) followed the procedure by Heiri et al. (2001). Magnetic susceptibility (MS) was measured by a portable susceptimeter ZHstruments SM-30 for the stratigraphic analysis of deposits. This characteristic depends on the concentrations and occurrence of magnetic particles. All the lithological methods were applied to deposits of the core 20770 to a depth of 0-6.5 m, each 10 cm.

Pollen analysis was carried out for 16 samples from the core 20770. Separation with heavy liquid (2.25 g cm⁻³) was used for pollen extraction from sediments. Calculation of pollen percentages was based on the total terrestrial pollen and spores sum.

Analysis of the composition of aquatic plant and animal organisms accompanied by their ecological analysis was applied for the reconstruction of lake and

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mire environments using the technique developed by N.V. Korde (1960). Analysis of bioindicators was made for two samples from the core 20769, but it can be correlated with the data on the core 20770. Sample 9 from the depth of 3.1-3.2 m and sample 10 from the depth of 3.25–3.35 m in core 20769 bracket a clear stratigraphic boundary at 3.21 m between silt and sapropel (gyttja). This boundary is also well defined in the core 20770 at a depth of 5.5 m.

3. Results and discussion

The results of lithological analysis of sediments from the core 20770 allow identifying some features of sedimentation and landscape dynamics. Moreover, analytical results agree with the beds identified in the description.

Coarse silt (0.01-0.05 mm) is a modal fraction of sediments, it dominates in all samples, except for the first. The proportion of fine silt and clay (0.005-0.01 mm) tends to increase with a depth. Two clear boundaries, marked by a change in granulometric composition, are 1) the transition from silt to sapropel at 5.5 m and 2) the coarsening of sapropel composition at 4.45 m.

The coarsening of the grain composition over geological time indicates either a decrease in the depth of the lake or a more active supply of the sandy component with runoff. This input may be the result of a restructuring of the meandering channels of the Toropa River or anthropogenic activities in the watershed that stimulate erosion.

The value of LOI 550°C varies in the range of 3.3-44%, with a maximum at 2.2 m depth in sapropel, and a minimum at 6.45 m depth in silt. That indicates the most organic-rich beds in the upper part of the core. The value of LOI 950°C changes in the range of 0.6-16.7%, with a maximum at 5.55 m depth in the roof of the silty layer, and a minimum at 1.45 m depth in sapropel. Loss on ignition also emphasizes only the boundary at 5.5 m noted above.

Magnetic susceptibility (MS) varies in the range of $0.035\text{--}0.138 \times 10^{-3}$ SI and generally decreases upwards. The saturation with magnetic minerals is higher in silt.

The results obtained for core 20770 indicate changes in sedimentation, as well as granulometric, chemical, and magnetic properties of sediments, sharply occurred at 5.5 and 4.45 m depths. The boundary at 5.5 m can be interpreted as a transition from minerogenic to organogenic sedimentation, which occurred at the turn of the Pleistocene and Holocene in lakes of the European part of Russia. Within the northwestern Russian Plain, predominantly minerogenic sedimentation often continued at the beginning of the Holocene, and a rapid change to the organogenic accumulation occurred after 10 cal. kyr BP (approximately at the Preboreal/Boreal boundary) both in large relict and small lakes (Subetto, 2009).

The results of pollen analysis of samples from the core 20770 confirm the correlation of the lacustrine silt layer at a depth of 6.5-5.5 m with the end of the

Late Glacial (or the Younger Dryas). The pollen spectra here demonstrate all the characteristic features of this interval: Non-Arboreal Pollen (NAP) makes up to 20% of the spectra, it contains a noticeable proportion of *Artemisia* and *Chenopodiaceae* pollen and a great variety of meadow plants. Simultaneous findings of pollen from the typical xerophyte *Ephedra*, heliophyte *Helianthemum*, and spores of such a cryophilic plant as *Selaginella selaginoides* are also indicative. Arboreal Pollen (AP) is represented by boreal tree species (*Betula* sect. *Albae*, *Pinus*, *Picea*, *Salix*) and microthermal shrubs (*Betula nana*, *Alnaster fruticosus*, etc.). Among aquatic plants, only the hardiest ones were noted, such as *Potamogeton*, *Myriophyllum*, and *Ceratophyllum* (leave spines).

The layer at a depth of 5.5-4.5 m is quite comparable in terms of pollen composition with the Boreal layers in this region. AP increases to almost 90% of the spectra and is represented mainly by birch and pine pollen. The amount of spruce pollen drops sharply, and pollen of broad-leaved species of oak forests appears (*Ulmus*, *Quercus*, *Tilia*, *Fraxinus*), as well as pollen of shrubs characteristic of the undergrowth in such forests: *Corylus*, *Lonicera*, etc. The proportion of spores of Polypodiaceae ferns is increasing; pollen of more heat-loving aquatic plants, such as *Nuphar*, *Hydrocharis*, occur here.

In the organic-rich sediment at a depth of 4.5-0.75 m, the composition of pollen spectra reflects further warming, probably accompanied by some decrease in climate continentality. The share of pollen of broad-leaved species increases, pollen of *Acer*, *Carpinus*, *Myrica* is noted; the proportion of alder and hazel pollen increases. The composition of aquatic plants becomes richer: pollen of *Nymphaea alba*, *N. candida*, *Trapa natans* is registered.

The pollen spectra of the upper 0.75 m of the sediment are close to those described above, however, there are some signs of anthropogenic impact: pollen of Cerealia and herbaceous plants, which can be considered weeds, appear: *Plantago*, *Rumex*, *Cannabis*. The share of NAP slightly increases, along with that of pine pollen, which may be associated with the cutting down of broad-leaved forests.

Analyses of biological composition confirmed quite different limnological and ecological conditions within sapropel at 3.10-3.20 m (sample 9) and silt at 3.25-3.35 m (sample 10) from the core 20769. In the first stage, the lake was much shallower, the water was rich in carbonates and contained less nutrients, as indicated by the abundance of the calcite-loricated alga *Phacotus lenticularis* and Ostracod shells. In the second stage, the water depth and the productivity of the lake increased, possibly as a result of the inflow enriched with nutrients, which is indicated by a greater diversity of algae and higher plant remains in sediment.

Combining all the proxies (GS, LOI, MS, pollen, bioindicators) we can distinguish four lithostratigraphic units corresponding to the main stages of Lake Shnitkino evolution in the Holocene: 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, 4) Recent time.

4. Conclusions

Based on all the data obtained we can reconstruct the landscape and climate dynamics of the lake Shnitkino basin. Four lithostratigraphic divisions with different granulometric, chemical, pollen, and biological composition are inferred. 1) Younger Dryas/Preboreal transition, 2) Boreal, 3) Middle-Late Holocene, 4) Recent time.

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Conflict of interest

The authors declare no conflict of interest.

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Paleolimnological changes in the composition of diatom complexes in the context of the Holocene Baltic Sea transgressions (Lake Zaychikhinskoye)

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ABSTRACT. The study examines the issues of changes in the level of the Baltic Sea over the past 10 thousand years. According to the data of domestic and foreign authors on time, there is no unambiguous data on the duration and level of littorina transgression, which is considered the largest during the Holocene period. By the research, with the financial support of the RFBR grant-graduate students No. 20-35-90089, studies of bottom sediments of lakes Goluboye, Bolshoye Molochnoye and Zaychikhinskoye are being carried out. The report presents the results of the diatom analysis of Lake Zaychikhinskoye. The main stages of the lake's development are determined, it is established that in the early Holocene its development was determined by the transgressive-regressive stages of the Baltic. At the initial stage, the reservoir was part of a deep oligotrophic Ancyclus lake. During the littorina transgression, the Baltic Sea level most likely did not rise to lake level in this area.

Keywords: diatom analysis, changes in the Baltic Sea level, littorina transgression, paleoreconstruction, Holocene

1. Introduction

The Karelian Isthmus, located at the junction of Lake Ladoga and the Baltic Sea, remains controversial in the issue of sea level change during the Holocene (Subetto et al., 1999). An important paleogeographic task of this territory is to establish the maximum level of littorina transgression, which occurred about 7,500 cal. l.n., as well as its duration and the number of such transgressions. The most detailed study of this issue will allow the method of studying the bottom sediments of lakes, since bottom sediments are one of the most important data sources capable of identifying local and regional natural and climatic changes (Kuznetsov et al., 2019).

The lakes of the Primorsky Lowland were flooded by littorina transgression 8 200 – 7 200 cal. BP. According to the bottom sediments of the Lakhtinsky swamp, 2 stages of transgression were identified, while no traces of transgression were detected in the Gluchoye Lake, which is located at the 9m mark, and in the Ozyornoye settlement. According to Lake Vysokinskoye, the highest coastline of the littorina Sea is marked at the level of 12-13m (Miettinen et al., 2007). There are also studies of the territory of the Luga Bay and the Narva Bay (Rosentau et al., 2013; Sandgren et al., 2004).

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2. Materials and methods

3 lakes on the Karelian Isthmus were chosen as the object of research: 2 in the north-western part and 1 in the south-western part. When choosing the objects of the study, was considered their geographical location and different heights above sea level were taken into account: Bolshoye Molochnoye 9m, Goluboye 11m and Zaychikhinskoye 12 m, which will allow more accurately determining the transgressive-regressive cycles of the Baltic Sea. In October 2017, field work was carried out on the lake. Blue, in July 2020, the study continued on the lakes Bolshoye Molochnoye and Zaychikhinskoye. Sampling was carried out from a raft, using a peat drill of different diameters (GOST 17.1.5.01-80, 1980) (Subetto, 2016). After removing the columns of bottom sediments, the cores were cleaned and packed for further transportation to the laboratory.

3. Results and discussion

Zone 1. At the base of the section, there is an alternation of sedimentation of greenish-brown interlayers of clay gitty and gitty clay. Diatoms during this period are characterized by an extremely low content of species, which indicates unfavorable

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habitat conditions for the development of diatoms. The presence of such species as *Aulacoseira islandica*, *Navicula scutelloides*, *Navicula jaernfeltii*, *Ellerbeckia arenaria*, *Cymbella sinuata* indicates the Early Holocene stage of development of the Baltic Sea – Ancylus Lake (Hedenström et al., 1999). A similar composition of diatom complexes was found in Lakes Goluboye and Bolshoye Molochnoye, located on the Karelian Isthmus north of Zaychikhinskoye at 27 km and 45 km, respectively. According to the data of the diatom analysis of Lake Goluboye, a stage of ancylus transgression was identified, which dates 10100-9700 cal. BP, after which the lake developed in isolation (Ludikova et al., 2020). In the sediments of the Nizhneosinovsky swamp, located 16 km east of Lake Goluboye, at 23 m, the age of ancylus deposits was about 9200 cal. BP (Subetto, 1999). The change of sedimentation from clay to gittyta indicates a change in natural conditions towards warming, however, based on diatoms, we can say that this period corresponds to the freshwater stage – Ancylus Lake. A small number of planktonic diatoms (10-25%) indicates a relatively small depth of the lake during this period.

Zone 2. The predominance of homogeneous gittyta in the lithological composition, as well as a significant increase in the content of diatoms and FDI (from 0.03 to 0.07) reflects the improvement of natural conditions in the direction of warming. Since the maximum percentage (up to 5%) of individual “ancylus species” (*Didimosphenia geminata*, *Ellerbeckia arenaria*, *Navicula scutelloides*, *Navicula jentzschii*) is observed in this zone, it can be argued that the ancylus period continues in this zone. Planktonic *Aulacoseira islandica* remains co-dominant in this zone (25-5%), along with an increase in epiphytes *Fragilaria pinnata* and *Fragilaria construense*. This fact can be explained by the relatively small depth of the lake, which made it possible for epiphytes to develop more actively after an increase in temperature. The proportion of halophilic diatoms increases due to such species as *Epithemia sorex*, *Epithemia turgida*, *Cyclotella radiosia*, *Fragilaria pinnata*. *Epithemia turgida* reaches 7% at a depth of 5.38 of the total content of diatoms, *Fragilaria pinnata* - 10% at 5.32m, but the proportion of *Epithemia sorex* and *Cyclotella radiosia* does not exceed 2% in the zone. The predominance of “ancylus species”, as well as the low content of halophiles according to N.N. Davydova (1985), suggests that the ancylus period is still continuing in this zone.

Zone 3. In the lithological composition there is a homogeneous dark olive gittyta, which is reflected in the composition of diatom communities. The complete reduction of the “ancylus species” indicates the isolation of the Zaychikhinskoye Lake from the Ancylus Lake. After that, the gradual increase in the share of *Aulacoseira ambigua* and *Aulacoseira granulata* to 77% and 42% in the zone, respectively, indicates an increase in the water level in the lake. Most likely, the waters of the Littorina Sea did not arrive during this period, since halophiles were reduced to the lowest values

throughout the section (0.018). According to data from Lake Goluboye, this period falls on 7,570 - 7,500 cal. BP and is distinguished by such species as *Epithemia sorex*, *Navicula tuscula*, *Mastogloia smithii*, *Navicula cari* (Ludikova et al., 2020). In Bolshoye Molochnoye Lake this period is characterized by the appearance of *Cyclotella radiosia*, *Epithemia sorex*, *Navicula cari*, *Fragilaria pinnata*, *Cyclotella schumannii*, however, the number of a single species is no more than 5% of the total number of species (Shatalova et al., 2021). Consequently, littorina transgression did not cause an increase in the water level in this lake. It can be estimated that at this time a channel opened between Zaychikhinskoye Lake and Pioneer Lake, which made it possible for a large amount of fresh water to flow from a lake located less than 1 km southwest of the studied one.

Zone 4. Above the section, the olive color of the gittyta is replaced by dark brown. Diatoms during this period are characterized by a monodominant *Aulacoseira ambigua* complex, the proportion of individual epiphyte species is also close to 0, which indicates the preservation of a high water level. *Cyclotella stelligera* began to develop in zone 4, reaching 6% of the total number of species in the upper boundary of the zone, being one of the leading species after the co-dominant *Aulacoseira granulata* (up to 20% by 499 cm) and *Aulacoseira subarctica* (up to 6% by 455 cm). Audra De Vault (2007) explains this feature in his study «Links Between Climate Change and the Abundance of *Cyclotella stelligera* in Alpine Lakes» by the ability of this species to develop well at high levels of UV- radiation and a reduction in precipitation. It can be assumed that *Cyclotella stelligera* attested the onset of a drier Subboreal period.

4. Conclusions

The results of the analysis of diatoms of Lake B. Molochnoye allowed reconstructing the dynamics of natural and climatic conditions in the Holocene in the northwestern part of the Karelian Isthmus.

At the beginning of the Holocene, the lake was part of a deep - water oligotrophic Ancylus lake. At the final stage of the Ancylus lake, an increase in the number of halophilic species was recorded, but their small total number and the predominance of «ancylus species» does not give grounds to assert the beginning of littorina transgression. This was followed by isolation from Ancylus Lake and an increase in the water level in Lake Zaychikhinskoye. But littorina transgression did not cause an increase in the water level in the lake, because during this period there were no halophilic diatoms at all.

Unlike the lakes Goluboye (11m) and Bolshoye Molochnoye (9m), where the level of littorina transgression was not much higher than the current height of the lake, lake Zaychikhinskoye, located at 12 m, was not at all affected by littorina waters (Ludikova et al., 2020).

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Conflict of interest

The authors declare that there is no conflict of interest.

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Relative sea-level variations indicated by micropaleontological data from small lake bottom sediments (Kandalaksha Bay, NW Russia)

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ABSTRACT. The results of the micro-paleontological study of bottom sediments from a small lake on the Kandalaksha Bay shore of the White Sea are reported. Three stages in the evolution of the lake basin: marine, transitional and lacustrine were recognized. The characteristics of their diatom complexes and palynological spectra were revealed. Marine-facies sediments were shown to be dominated by poly- and mesohalobes, their share in the transition facies is twice as small, and freshwater diatom complexes contain up to 10% halophiles. Facies were shown to be reliably identified, using the pollen and spores of distinctive species indicative of certain ecological conditions. Non-pollen palynomorphs (algae *Pediastrum*, *Botryococcus* and sponge spicules) can be used for identifying various facies. These data will be used later to more reliably and objectively reconstruct variations in relative sea level and the sea shoreline migration in the Holocene. A decrease in sea level was established at the turn of 7200 cal. years and the isolation of the lake from the sea occurred about 6700 cal. years ago.

Keywords: Holocene, bottom sediments, pollen analysis, diatom analysis, White Sea

1. Introduction

Shoreline migration results from the interaction of many factors: the glacioisostatic uplifting of the earth crust, eustatic variations in ocean level and tectonic movements proper in the Kandalaksha Graben area (Kolka et al., 2015). The study of White Sea shoreline migration is essential for approaching various problems in the paleogeographic reconstruction of the environment on the sea shore. A number of works have been devoted to changing the position of the coastline in this area (Kolka et al., 2015; Korsakova et al., 2016).

Bottom sediments from five lakes located at an altitude of 4 to 37 m above sea level (a.s.l.) were studied using micropaleontological methods. The isolation from the White Sea paleobasin and evolution of one of them are discussed below. Obvious indicators of the position of the coastline of the sea during the isolation of lake basins are complexes of diatoms. The article demonstrates that pollen, spores of certain taxa and non-pollen palynomorphs can also be used in the study of basin isolation.

2. Materials and methods

A nameless lake (37 m a.s.l.) selected as an object for this investigation is located on the Karelia

coast of Kandalaksha Bay of the White Sea near at the mouth of the Keret River. For defining stages in sedimentation we investigated bottom sediments by diatom and palynological analyses. Methods for processing and studying samples by diatom analysis are described in (Shelekhova et al., 2021). Samples for palynological analysis were treated using generally accepted procedures (Pyl'tsevoy analiz, 1950). A study of non-pollen palynomorphs (*Botryococcus* and *Pediastrum*) was also carried out.

3. Results and discussion

It has been shown that the bottom sediment sequences are represented by three facies: marine, marine- to lacustrine transition and freshwater.

Upon silty clay sedimentation with mollusk shell inclusions in the thickest **marine facies**, exposed by drilling, the diatom complex consists of polyhalobes (95-60%), mesohalobes (10-20%) and halophiles (4-10-15%). The percentage of polyhalobes in the upper portion of marine sediments decreases to 60%, while meso- and halophiles increase to 30%. Indifferent freshwater forms make up about 10% of the complex also comprises. Structurally, the marine facies falls into two subfacies. The first one, dominated by the

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planktonic polyhalobic species (90-95%) of the genera *Hyalodiscus*, *Thalassiosira* and *Chaetoceros*, as well as the polyhalobic bottom forms *Trachyneis aspera* etc., formed in a deeper-water basin. During a second marine subfacies, when silt accumulated, the percentage of planktonic *Hyalodiscus* sp. declined to 5-25%. Centric “deep-water” marine forms were succeeded by the littoral *Paralia sulcata* and littoral pennate forms of the genera *Grammatophora* (40%), *Trachyneis* et al., as well as the species of the genus *Tribionella* (about 10%). Consequently, the sea level also decreased at that time.

Marine-facies sediments were shown to contain the pollen of halophytic plants from the maritime saline White Sea ecotopes, such as *Plantago maritima*, *Atriplex nudicaulis*. There is pollen, according to its morphological features, belonging to the type Aster. But in terms of ecology and geographical distribution, *Tripolium vulgare* is the most compatible. The abundance of sponge (Porifera) spicules suggests sedimentation in a marine environment, because most sponge species prefer a marine habitat. It should be noted that they are less abundant in the upper part of the facies, while halophytic plant pollen occurs more often.

In the **transition** layer 2 cm thick (gyttja with silt impurity), the proportion of poly- mesohalobes and halophiles decreases by half, not exceeding 50% in total. All of the above species make up from 2 to 10%, many are few in number. The other part of the complex consists of indifferent freshwater species from the genera *Aulacoseira* sp., *Cyclotella* sp., *Staurosira* sp., *Tabellaria* sp. and others. During the formation of this facies, the reservoir underwent a transition from a sea bay to an isolated lake with sea water in the bottom layer, when sea water entered it by tides. Since the marine environment has been replaced by freshwater, the continuous curve of pollen from halophytic plants has dropped out of the palynological spectra and wedged out. There are few microfossils of plants from freshwater reservoirs (*Nymphaea*, *Nuphar*, *Sparganium*) and remains of *Pediastrum* algae. Apparently, the plants that produced this pollen grew in the shallow zone of the already desalinated bay. The increase in Cyperaceae pollen is associated with the emergence of waterless saline habitats. They were inhabited by sedge, many species of which are halophytic. According to another scenario, the shallow zones of the isolating reservoir could be inhabited by glycophytes of this family. Sponge spicules were not found in transitional facies. The thinness of the deposits, indicating a transition from marine to freshwater conditions of sedimentation, indicates a rapid regression of the sea and isolation of the lake. Radiocarbon dates obtained from the gyttja layer with an admixture of silt (Tolstobrov et al., 2021) indicate a sea level decrease of 7200 cal. y. a. and the lake sharply separated from the sea 6700 cal. y. a.

The **freshwater** facies is represented by sapropels (gyttja) in which the diatom complex consists of 80-90% freshwater species from the genera *Aulacoseira* sp., *Cyclotella* sp., *Staurosira* sp., *Tabellaria* sp., *Anomoeoneis* sp., *Frustulia* sp., an insignificant amount (up to 2 %) species of the genera *Epithemia*, *Pinnularia*, *Navicula*, *Eunotia*, *Gomphonema*; single

poly-, mesohalobes and halophiles. Up the section, the proportion of halophobes increases, and the reservoir becomes “acidified”. The sediments contain the pollen of plants growing in freshwater bodies (*Myriophyllum alterniflorum*, *Nuphar luteum*, *Nymphaea alba*, *Typha angustifolia*, *Sparganium*), *Isoetes* spores and the algae *Pediastrum* and *Botryococcus*. The amount and diversity of pollen and spores are not great. It should be noted that lakes in North Karelia typically display the poor species composition of higher aquatic vegetation.

4. Conclusions

Diatom and spore-and-pollen analysis has revealed sediments of various sedimentation facies. A marine facies is indicated by diatoms dominated by marine poly- and mesohalobes, the pollen of halophytes from the maritime salinized White Sea ecotopes and sponge spicules; in the transition zone, the percentage of marine diatom species decreases by 50%, halophyte pollen disappears from spectra, and sediments from the separated lake contain the pollen, spores and algae of freshwater bodies. The results of the combined study of lake bottom sediments have shown that about 7200 cal. y. a. it was a fairly deep sea bay. 7200-6700 cal. y. a., the sea level declined abruptly and 6700 cal. y. a. the bay separated completely from the sea.

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Conflict of interest

The authors declare no conflict of interest.

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Barents Sea coastline dynamics in the Holocene in the Kola region: grain-size and LOI analyses of lake sediments

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ABSTRACT. The research of Barents Sea coastline dynamics is based on isolated basins method: bottom sediments were sampled in the chain of lakes located in the area of Musta-Tunturi ridge by the Barents Sea coastline and on the isthmus between Sredniy Peninsula and mainland part of the region, the expedition took place in July 2021. This report presents common results of grain-size and LOI (losses on ignition) analyses of 4 lakes' bottom sediments. Deepest uncovered sediments are associated with marine genesis and characterized by the biggest average particle diameter and the lowest percentage of organic matter. Layers previously supposed as transgression sediments also have dissimilar grain-size structure from other layers of the core and low percentage of organic matter.

Keywords: bottom sediments of lakes, sea level change, Barents Sea, Late Glacial, Holocene

1. Introduction

The territory of the northeast of the Fennoscandian Shield is a classic area for studying changes in the position of the sea coastline associated with neotectonic movements of the Earth's crust. In recent years, the method proposed by Scandinavian scientists (Donner et al., 1977) has been used to determine the nature of the movement of the sea coastline. The method is based on determining the spatial and temporal position of the insulating contact – the transition zone from the sea to the freshwater lake, in the columns of bottom sediments from the basins of lakes. Such works were carried out on the Barents Sea coast of the Kola region in the areas of the village Dalnie Zelentsy (Snyder et al., 1997), Nickel (Corner et al., 1999) and Polyarny (Corner et al., 2001), in the valley of the Tuloma River (Tolstobrov et al., 2015; 2016), as well as on the White Sea coast of the Kola Peninsula and Karelia (Kolka et al., 2013; 2014; 2015). At the same time, there remain areas for which there is no data on the amplitude and rate of elevation of the Earth's surface.

2. Materials and methods

In July 2021 the expedition took place and bottom sediments of 8 lakes on interval of elevations 11.0-83.5 m were sampled. Four of them that have been chosen to be analyzed on LOI and grain-size are located on elevations: SR-1 (11.0 m), SR-5.2 (27.0 m),

SR-2 (31.2 m) and SR-7.2 (83.5 m). Figure 1 shows the location of the fieldwork area. These samples were delivered to Saint Petersburg. Lithology was described in the previous abstract about first results of this expedition (Tolstobrov et al., 2021).

Both analyses were performed according to the standard methodology (GOST 17.4.4.02-84, 2008) in the laboratory of Rational Environmental Management of the Department of Physical Geography and Environmental Management of the Faculty of Geography of Herzen University. To perform the LOI analysis, the samples were ignited at 550°C, prepared and weighted before and after the ignition to count the losses of weight. It is interpreted as the loss of organic matter (OM). After comparison of different methods the Estonian one was chosen (Vaasma, 2008): every sample was mixed with 40% hydrogen peroxide and heated up to 80°C until the reaction stopped. While the reaction continues it is important to keep adding hydrogen peroxide. Grain-size analysis was performed using LaSca-1C Laser Particle Size Analyzer. The measurement was carried out three times, and their results were averaged.

3. Results and discussion

SR-1 (11.0 m) is characterized with regression sequence of facies – marine, transitive and lake facies change each other showing the regression of the sea. The transition zone between gyttja with silt and silt

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Fig. The location of the fieldwork area (A) and the location of the studied lake basins (B). Contour interval = 20 meters. Lake basins are marked with red circles (Tolstobrov et al., 2021).

sediments correlates with peaks of increasing average particle diameter and percentage of organic matter. The average diameter a bit increases from 10 to 15 μm in these samples. It allows us to suppose the fast change of hydrodynamics of the basin. Soon the results of radiocarbon dating for these layers will also be received. SR-7 (85.3 m) with 7 meters of homogeneous gyttja and 0.3 m of silt with sand has peaks of average particle diameter and the lowest percentage of organic matter in the deepest layers associated with marine sedimentation.

SR-5.2 (27.0 m) has a more complex sequence of facies: marine – gyttja – marine – transitional – gyttja. This sequence reflects the repeated penetration of sea waters into the basin of the lake. Sea level rise is probably associated with the transgression of the sea in the Middle Holocene (Tolstobrov et al., 2021). SR-2 is located close to SR-5.2 and only 4 meters higher, but the transgression horizon wasn't observed. Brown gyttja in this core is divided two times: by thin grey silt layer and thin grey sandy layer with only 4% of OM while the layers deeper and higher contain nearly 30-40% of organic matter, except deepest marine sediments. The first one isn't correlating with some change in the percentage of some fractions, but the second one correlates with pretty large increase of average particle diameter – from 10 to 62 μm . It could be caused by some catastrophic event, probably it could be the Storegga tsunami in the Middle Holocene (Bondevik et al., 1997; Romundset and Bondevik, 2011): radiocarbon dating results will help to prove or disprove this hypothesis later.

4. Conclusions

Gyttja of the studied lakes on average contains about 30-60% of OM, but the lower horizons of all four lakes contain no more than 10%. In the deepest horizons uncovered this value is approximately about 1.5%, which is not typical for lake sediments.

Thus already at the stage of field description and the first laboratory analysis, an assumption about the marine conditions for the formation of sediments in these horizons was made. To determine exactly

whether they are of marine origin diatom analysis will help, samples for it were also carried. Quick look at diatoms in some samples of the lower horizons of all four lakes showed that salt-water species of diatoms are found in the sample of the clay and sand horizons. In the transitional gyttja/silt – only freshwater ones, which indicates the isolation of the lakes' basins from the sea and the subsequent formation of freshwater conditions in them.

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Fecal stanols in sediments of Lake Shira (Siberia, Russia) as a proxy of human impact on surrounding territory in the Late Holocene

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ABSTRACT. The analysis of biochemical markers of fecal intake is one of the newest trend in paleolimnology. Stanols (cholestanol, stigmastanol, etc.) produced by the intestinal microflora from sterols are indicators of fecal influx into a water body. Coprostanol is synthesized in the human intestine, therefore, the presence of coprostanol in bottom sediments can be used to reconstruct the dynamics of the population in the lake watershed and to evaluate the dynamics of fecal pollution. Using the gas chromatography method, we were the first to estimate the content of cholestanol and coprostanol in the dated core layers of the bottom sediments of Lake Shira. The raised proportion of coprostanol indicates an increase in fecal anthropogenic inflows into the lake in the modern period, as well as in earlier periods of the history of Khakassia, in particularly during the existence of the Yenisei Kyrgyz state (VIII - XIII centuries CE).

Keywords: fecal stanols, coprostanol, gas chromatography, lake sediments, Lake Shira

1. Introduction

The study of fecal compounds in lake sediments as a biochemical marker is one of the newest trend in paleolimnology. These markers include stanols, which are produced by the intestinal microflora from sterols. Stanols persist in bottom sediments for thousands of years that is why they are valuable proxy of animal and human presence in lake watershed (White et al., 2019; Vachula et al., 2019).

Despite similar stanols are synthesized in mammals, the percentage of different stanols varies in humans and animals. Coprostanol and epicoprostanol are produced mostly by human microflora. Therefore, these specific stanols are used to reconstruct the population history of water bodies as well as to assess the anthropogenic load (D'Anjou et al., 2012; Argiriadis et al., 2018).

2. Materials and methods

Lake Shira (54°30' N, 90°11' E) is located in the Republic of Khakassia, 15 km from the regional center Shira. The lake has oval shape, its size is 5.3 × 9.3 km, its area is 35.9 km², its maximum depth is 25.4 m (2021). Zhemchuzhny settlement and the resort "Lake

Shira" are located on the lake shore. In summer, the lake is a popular place for vacation. Many campsites are based on its shores. A core 80 cm long was sampled using a UWITEC gravity sampler (Austria). The age of the bottom sediments was previously determined for another core based on radioisotope analyzes (Kalugin et al., 2013). Stanols were extracted from dried samples with ethanol: chloroform (3:7) followed by silylation (Andaluri et al., 2017). The stanols were analyzed on an Agilent 6890N gas chromatograph using an Agilent 5975C mass spectrometer as a detector. External standards for cholestanol and coprostanol were used to estimate concentrations.

3. Results and discussion

Cholestanol and coprostanol were found along all core depth. Cholestanol is an indicator of general fecal contamination, while coprostanol is a characteristic of human feces. The proportion of coprostanol in the total amount of coprostanol + cholestanol increased in the layers of the VIII - XII centuries AD in the heyday of the Yenisei Kyrgyz state, and in the XVII - XIX centuries during the development of these lands by the Russian population (Fig.). The largest proportion of coprostanol was observed in the modern period, which relates

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obviously to an increase in anthropogenic load because of the resort and the use of the lake as a place for summer vacation (Fig.).

4. Conclusions

The raised proportion of coprostanol in the modern period indicates an increase in anthropogenic fecal influx into Lake Shira. In earlier periods of the history of Khakassia, particularly during the existence of the Yenisei Kyrgyz state (VIII - XIII centuries AD), an increase in coprostanol share indicates a possible increase in human presence in the Lake Shira drainage basin.

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Conflict of interest

The authors declare no conflict of interest.

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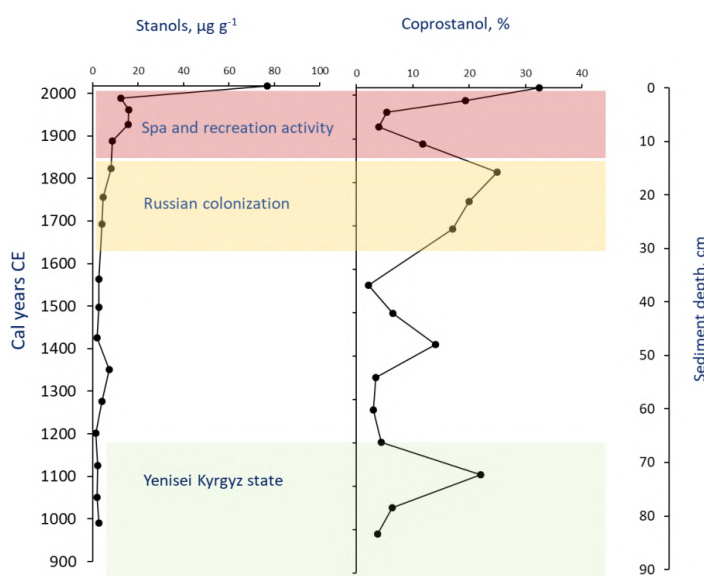


Fig. Distribution of fecal stanols and proportion of coprostanol in the core from Lake Shira. The periods of the history of Khakassia are highlighted in color.

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Short communication

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Climate signals in the Holocene bottom sediments of shallow saline lakes of the Southwestern Siberia

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ABSTRACT. We present the results of the study of the Holocene sediments from two shallow lakes of different salinity located in the East Baraba lowland (Southwestern Siberia). The research methods: X-ray diffractometry (XRD), IR spectroscopy, laser particle size analysis, AMS dating, etc. By the mathematical modeling of complex XRD patterns Mg-calcites with different Mg contents, excess-Ca dolomite and aragonite have been established in the assemblages of carbonate minerals. Based on studies of mineralogical-crystallochemical features and quantitative ratios of Ca-Mg carbonates the evolution stages of lakes corresponding to the regional cycles of aridization/humidization were identified and the correlations with global climatic events were carried out. The obtained results is an important source of new information about the Holocene climate in the Southwestern Siberia.

Keywords: saline lake, bottom sediments, carbonates, XRD analysis, Holocene, paleoclimate, Western Siberia

1. Introduction

One of the key sources of information about the environmental and climate changes in intracontinental regions is represented by the sections of bottom sediments from lakes characterized by different mineralization and trophicity (Last, 2002). Among the numerous shallow lakes of the Western Siberia, a specific group consists of saline and brackish basins confined to areas dominated by arid and semiarid climatic conditions. The Holocene sedimentary records are of special interest because, first, they have not undergone significant post-sedimentary transformations and, second, the Holocene environments are often considered to be close analogues of the modern conditions and/or potential analogues of the future ones. Associations, compositions, and crystalline structures of authigenic components of lacustrine sediments carry information about the water chemistry, temperature and other parameters, which are determined in the end by the regional climate. In turn, changes in the characteristics of authigenic minerals allow us to identify the intervals of a stable environmental state in the dated sections, to establish the boundaries marking the changes of natural settings, and to correlate the revealed climate conditions to the already known regional and global

paleoclimatic records. This work aimed to obtain a high-resolution Holocene climate record of the Southwestern Siberia from the sedimentary sections of two shallow saline lakes with carbonate sedimentation: Lake Itkul and Lake Bolshoy Bagan. The author's approach to paleoclimatic reconstructions is based on the detailed mineralogical and crystallochemical studies of the lake sediments, the results of which are considered in combination with data from other types of analysis.

2. Materials and methods

Both lakes are located in the East Baraba lowland. It is a plain covered with alluvial-lacustrine deposits and situated within the forest-steppe landscape zone in the south of the Western Siberia. The basin of Lake Itkul consists of the main depression and a shallow bay in the western part. The average depth is ~1.5–1.8 m, surface area of the lake is 15.1 km², water is hydrocarbonate sodic with total mineralization of 2098 mg/L (brackish waters), pH = 9.1. Lake Itkul is replenished by spring high waters and atmospheric precipitation. The water surface area of Lake Bolshoy Bagan is about 5.6 km² with the depth in the central part of the basin 0.65 m. The waters of the Bolshoy Bagan belong to brines with a total mineralization of 282 g/L and pH = 7.32. The

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lake is the final drainage basin of the Bagan River.

The samples were studied by X-ray diffractometry (XRD), IR spectroscopy, laser particle size analysis, X-ray fluorescence spectrometry and radiocarbon dating (AMS). The differential diagnostics of carbonate minerals in the lake sediments was made by mathematical modeling of high-resolution XRD profiles (Solotchina and Solotchin, 2014). Decomposition of diffraction profiles of Mg-calcites into individual peaks using the Pearson VII function revealed the positions, integrated intensities, and quantitative relations of the peaks (Fig.). The MgCO_3 content was determined from the calibration curves (Deelman, 2011).

3. Results

The total length of the Lake Itkul core is 180 cm, the uppermost 162 cm of which are lacustrine sediments proper, whereas the lower 18 cm are represented by underlying loess-like deposits. The main minerals in the Lake Itkul sediments are quartz, carbonates and plagioclase. Subordinated minerals are clay minerals (illite, chlorite, kaolinite) and K-feldspar in the entire section. Episodically appearing minerals are pyrite and amphibole; traces of gypsum and ilmenite (Solotchina et al., 2019). The core taken in the central area of Lake Bolshoy Bagan is 362 cm long. The lacustrine pelite-silt sediments are 284 cm thick. The underlying interval of 284-362 cm is mainly composed of sandy loams with a small admixture of gypsum and interlayers of fine-grained sand. Quartz, feldspars, mica, chlorite, occasional amphibole and pyrite represent the terrigenous minerals in the Bolshoy Bagan sediments. Among the authigenic minerals, halite, gypsum and Ca-Mg carbonates prevail at the top of the section aragonite and small amount of Mg-siderite occurs in the middle. The age of the base of lacustrine sediments in Lake Itkul is 8,500 cal. yrs, in Lake Bolshoi Bagan is 9,000 cal. yrs corresponding to the end of the Boreal.

Among the carbonate minerals low-temperature carbonates of the calcite-dolomite series dominate in bottom sediments, aragonite is present in a subordinate amount. It is known that the precipitation of carbonates of the calcite-dolomite series is determined by a combination of a number of factors: the Mg/Ca ratio in water, its total carbonate alkalinity, salinity, pH value, temperature, and organic productivity. All these parameters are under control of the water balance, which in its turn depends on climatic conditions. Previously, we showed (Solotchina and Solotchin, 2014) a humid climate promotes the formation of low-Mg and intermediate Mg-calcites, its aridization is accompanied by the precipitation of high-Mg calcites and Ca-dolomites. Diagnosis of carbonates is carried out by the most intense reflections ($hkl = 104$) in the range of angles 26.0–32.0 $2\theta\text{CuK}\alpha$ (Fig.). Aragonite (orthorhombic symmetry) is concentrated in the chemogenic part of the sediments. It is characterized by an increased content of Sr compared to the reference. Co-precipitation of aragonite with Mg-calcites is possible with increased carbonate alkalinity and salinity of waters.

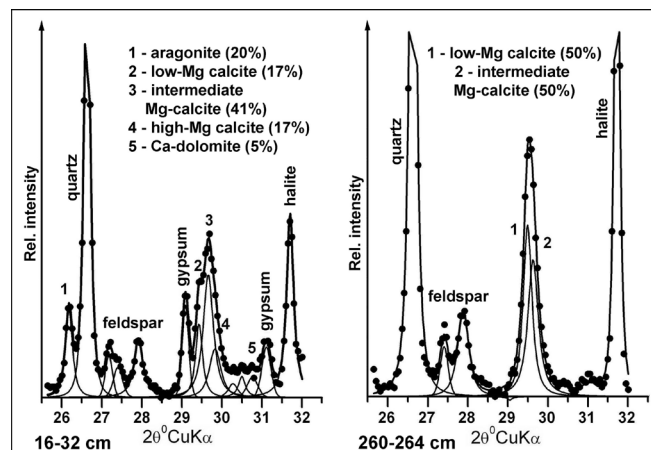


Fig. 2. Modeling of XRD patterns of carbonates from the sediments of Lake Bolshoy Bagan. It is clearly seen there is a good fit between integrated model patterns (solid line) and experimental ones (dots). Diffraction peaks of individual phases are described by the Pearson VII function. The total carbonate content in a sample is assumed to be 100%.

4. Discussion and conclusions

Based on studies of mineralogical-crystallochemical features and quantitative ratios of Ca-Mg carbonates in sections we have identified stages of evolution of both lakes depending on regional climatic changes. In general, these stages coincide with the well-known climatic phases of the Holocene (Blytt-Sernander classification). The formation of the lakes occurred at the end of the Boreal which was relatively humid in the East Baraba territory. During the Atlantic, content of carbonates and their Mg-content in sediments was increased that seem indicate about dry condition. In distribution of carbonates at this stage there are significant peaks (up to 50% in Lake Bolshoy Bagan and up to 80% in Lake Itkul) which, in our opinion, correspond to the global climatic the Bond 4 event. Variable ratios of carbonate phases in the Subboreal sediments indicate unstable environmental conditions but in general, this stage was likely colder than the previous.

According to the carbonate records, the subatlantic was characterized by a moderately warm and humid climate. However, a maximum of carbonate content (up to 50%) was observed in Lake Bolshoy Bagan at ~1400 years which is probably related to the short-term cooling and drying known as the Bond 1 event.

Thus, the lithological and mineralogical studies of bottom sediments of two saline lakes supplemented by the results of several other analyses allowed to obtain high-resolution of the Holocene climatic records of the East Baraba lowland. The evolution stages of both basins according to the regional cycles of aridization/humidization were identified, correlations with global climatic events were carried out. It should be noted that the bottom sediments of Lake Bolshoy Bagan with supersaline water (brine) were successfully used to paleoclimate reconstructions for the first time. The obtained results became an important source of new information about the Holocene climate in the Southwestern Siberia.

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Conflict of interest

The authors declare no conflict of interest.

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Comparison of mineralogy and geochemistry of the suspended matter of waters from river runoff and snow cover of Lake Onega

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ABSTRACT. The data of mineralogy and geochemistry of suspended matter in water (filtered 0.45 microns), suspended solids (from filters of snow-fallen, river, lake waters) are compared from different parts of Lake Onego. We revealed the mineral composition of the suspended matter differs in the absolute contents of the suspended matter in the water, the ratio of the amount of organic matter in it, the presence or absence of aggregates of technogenic genesis and their quantity. The geochemistry of suspended matter from river's waters is highly similar to the geochemistry of suspended matter from water in various areas of Lake Onego, but significantly differs from the suspended matter of snow-covered waters.

Keywords: Lake Onego, suspended matter, water, snow cover, geochemistry, mineralogy

1. Introduction

To gain new knowledge about the suspended matter entering the bottom sediment of Lake Onego, the mineralo-geochemical composition of the suspended matter from river waters and snow cover has been studied. The purpose of the work is a comparative analysis of the mineralo-geochemical composition of modern suspension coming from the river and snow runoff and suspension of the water in various areas of Lake Onego.

2. Materials and methods

The samples of water's rivers and lake, snow accumulated over the entire period of snow cover were selected in 2020-2021 in different parts of Lake Onega (Central and South Onega, Unitskaya, Kondopoga, Petrozavodsk Bays) and in 9 estuaries of tributaries (among them Vodla, Shuya, Suna which give 68% of the water flow into the lake) and at the source of the Svir river. The suspension from the water was separated by vacuum filtration with specially prepared pre-weighted membrane filters (0.45 µm). The thin

colloidal phase remains in the filtrate. It is known that this phase contains a part of the metals that form organic complexes with humic matter. Analytical studies were carried out at the Analytical Centre for Multi-Elemental and Isotope Research of the SB RAS (IGM, Novosibirsk), the Laboratories of Hydrochemistry, Hydrogeology and Paleolimnology of NWPI KRC RAS (Petrozavodsk). The major and trace element compositions were studied using the atomic absorption and the ICP-MS methods. A detailed study of the structural features, the morphology at the level of individual mineral grains of the *suspended matter* was carried out using scanning electron microscope (SEM). The specific modification of the equipment used an Si(Li) energetic detector, and enabled to carry out a quantitative chemical analysis on micro volumes.

3. Results and discussion

The studied suspended matter samples of rivers and snow are grouped according to the geographical location of river catchments taking into account the geological and geomorphological structure of the lake basin and the areas of Lake Onega into which they flow.

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A previously published article presents the results of a detailed study of the chemical composition of waters and suspended matter of Lake Onega (Strakhovenko et al., 2021; Kulik et al., 2022). SEM of the studied suspended matter samples of rivers showed similar spectra of minerals, but their ratios differed. The uneven distribution of particles by size, degree of their rolling as well as different ratios of the mineral and organic parts of the suspended matter were revealed. It is established that the mineral part of the detrital material is represented by an aggregated substance of lithogenic particles of different dimensions in association with shells and biodebris of diatoms. The suspended material is represented by mineral particles (1-5 μm in size) grouped into aggregates (with a diameter of 15-40 μm) which consist of quartz grains, irregular grain clots of hydroxides and carbonates of Fe, Mn, plagioclase (albite, oligoclase, andesine), potassium feldspar, muscovite, illite, chlorite. It is important to note that illite and chlorite with Mg and Fe content in approximately equal amounts prevail sharply in the suspension of rivers, and their large leafy aggregates begin to be replaced by their ferruginous varieties. The mineral composition of the suspension in one river depends slightly on the season of the year and between rivers differs in the absolute content of the suspension on the filter and the ratio of the amount of basic minerals in it, the dimension, the presence or absence of grains of unusual composition, and the morphology of the excretions of aggregates of iron minerals. The jelly-like aggregates of Fe and Mn oxides/hydroxides are present in significant quantities in the mineral matter of all rivers, their amount increases significantly relative to other of the Lososinka, Vytegra, Sheltozerka rivers. Anthropogenic particles in samples of the suspended matter of river waters are sparsely represented, mainly they are individual small (from 2 to 25 μm) irregularly shaped grains with a chemical

composition that does not occur in nature and/or have an unusual morphology. The largest number of these particles was found in the suspension of the Suna, Andoma rivers: large and small grains of irregular shape (Zn-Ni-Cu and Ni-Sn). SEM of the studied suspended matter samples of snowmelt waters showed an uneven distribution of lithogenic particles of different dimensions and degree of pelletizing (mainly sharp-angled irregularly shaped particles ranging in size from 1 to 8 μm) and their ratios with organic matter, the amount of which varies from 5-10% and is mainly represented by fragments of shells of diatoms and plant residues (size from 5 to 20 μm). Among the mineral particles grouped into aggregates (up to 80 μm in size), grains of quartz, plagioclase (albite, oligoclase), potassium feldspar, muscovite, biotite, actinolite, illite and chlorite ($\text{Mg} \geq \text{Fe}$). Grains of diopside, enstatite, epidote, titanite, magnetite, ilmenite, garnet and some other accessory minerals are present in significant quantities in the mineral matter. All samples show the aggregates of siderite with a columnar structure and small crystals of rhombohedral habit. Technogenic aluminosilicate microspheres, spheres of combustion of ferrous composition and large individual grains of various shapes of native iron with chromium, native lead with nickel, chromium, and copper with aluminum or zinc (particle size from 2-5 to 50 μm) were detected in quantities up to 10% of the total volume of suspension samples. A comparison of the geochemical composition of the suspended matter of the waters of the tributary rivers, snow and lake in each individual area revealed that the composition of the suspended matter of the rivers and the lake's water is not significantly distinct in trace elements with a completely different spectrum for snows (Fig.). Comparison of the average content of elements in suspended matters from different parts of lake Onega, rivers and snow normalized by concentrations of the

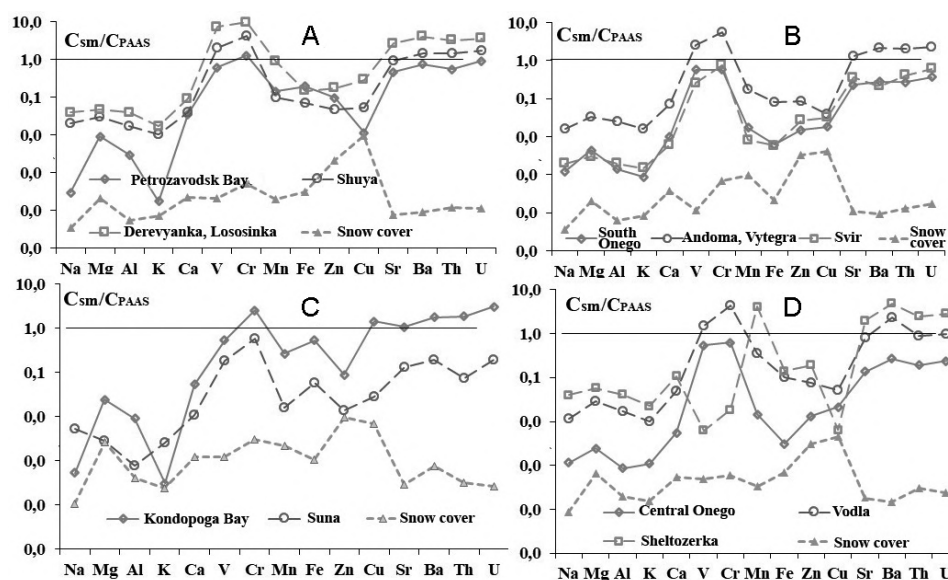


Fig. The spectrum of element contents in the suspension of the waters of the rivers, snows and Lake Onega, normalized to PAAS: A - Petrozavodsk Bay, r. Shuya, Derevyanka, Lososinka; B - South Onego, r. Andoma, Vytegra, Svir; C - Kondopoga Bay, r. Suna; D - Central Onego, r. Vodla, Sheltozerka.

Post-Archaeon Australian Shale PAAS (Taylor and McLennan, 1988) allowed us to establish that snowmelt waters are characterized by high concentrations of Mg, Zn, Cu, Cr (both in filtered water and in suspended). The content of trace elements of the suspended matter of the rivers in terms of dry matter relative to the level of their concentrations in the suspensions of the rivers of the World (Savenko, 2007; Shevchenko, 2006) are characterized by an increased content of Cu, Zn, Mn, Fe, Mo, Cd, Sb and Pb, the remaining metals are at a comparable level. Basically, the predominant form of finding elements in the water of rivers, snows and Lake is dissolved + colloidal (Kulik et al., 2022). Only in Kondopoga Bay, the suspended form for the studied metals sometimes prevails over the dissolved + colloidal form with maximum amounts of suspension in water.

4. Conclusions

For the first time, a study of the mineral composition of the suspended matter of the waters of the rivers, snow cover in comparison with the suspended matter of the waters of the areas of Lake Onego into which they flow was carried out. It was revealed that the mineral composition of the suspended matter entering the lake is weakly dependent on the season of the year and differs in the absolute contents of the suspended matter, the ratio of the amount of organic matter in it, the presence or absence of aggregates of technogenic genesis and their quantity. The suspended material in all areas of Lake Onego is enriched with quartz, feldspar, mica, hydroxides and iron carbonates, illite and chlorite ($Mg \geq Fe$). Among the technogenic grains, microspherules of ferruginous or aluminosilicate composition predominate sharply.

It has been established that the geochemistry of suspended matter from river's waters is largely similar to the geochemistry of suspended matter from water in various areas of Lake Onego with a significant difference from the suspended matter of snow-covered waters. The high concentrations of Mg, Zn, Cu, Cr and Hg detected in the suspended matter correspond to the

presence of anthropogenic particles entering the waters due to the atmospheric transport. The proximity of metallurgical plants of the Kola Peninsula may cause the increased intake of particles of technogenic genesis.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Reconstruction of the coastline of the Barents sea (the Kola Peninsula) during the Late Glacial and Holocene

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ABSTRACT. Comprehensive studies (lithological and micropaleontological) of bottom sediments from nine lakes at the Teriberka Village (the Kola Peninsula, Northwestern Russia) were carried out. The sediments formed after an isolation from the sea was dated. Based on these new data, a preliminary sea-level curve for the study area was constructed. The sea-level curve indicates several phases evolution of the Kola coast during the Late Glacial and Holocene. Rapid drop (~40 mm per year) of a sea-level was occurred ca. 11,500 cal. years BP. The sea level gradually elevated between ca. 11,000 and 7,600 cal. years BP (the Tapes transgression). Since ca. 7,300 cal years BP, the sea level slowly decreases by 2–3 mm per year.

Keywords: lake sediments, diatoms, radiocarbon age, sea-level changes

1. Introduction

The northeast of the Fennoscandian Shield is a classic study area for relative sea level changes caused by glaciostatic adjustment of the earth's crust. In the last 20 years, a method proposed by Scandinavian scientists (Donner et al., 1977) has been used to determine the rate of change in the position of the sea coastline. This method is based on determining the spatial and temporal position of the transition zone from the sea to a freshwater lake in bottom sediments from lake basins. Earlier work was carried out on the Barents Sea coast of the Kola region in the areas of Dalnie Zelentsy (Snyder et al., 1997), Nikel (Corner et al., 1999) and Polyarny (Corner et al., 2001), in the Tuloma River (Tolstobrov et al., 2016). However, there are many areas for which data about sea level changes are not available. This work presents new data about changes of the sea coastline at the Teriberka village (Kola Peninsula, Russia). On the basis of new lithological, micropaleontological and chronological data, a preliminary curve of relative sea level change was constructed.

2. Materials and methods

The material for the work was the bottom sediments from 9 lake located at altitudes from 4 to 58 m on the Murmansk coast of the Kola Peninsula near the Teriberka Village. For each lake, lithological studies, diatom analysis and radiocarbon dating of bottom sediments were made. Sediments cores were

taken from ice-covered lakes in April, 2013, 2016 and 2018, using a piston corer with 54-mm diameter. The sediments were described in the field inferred from their visually recognizable features (grain-size, lithology, colour and structure). Diatom analysis was based on standard methods. Taxa names are provided by the AlgaeBase data (Guiry and Guiry, 2020). Radiocarbon dating has been done at the laboratory of the St. Petersburg State University and at the laboratory of the Geological Institute of the Russian Academy of Sciences using the traditional scintillation method (Arslanov, 1987). Radiocarbon dates were calibrated to calendar years using the OxCal 4.4 calibration program (Bronk Ramsey, 2020).

3. Results and discussion

A transition from marine to freshwater sediments was found in the bottom sediments of studied lakes. The marine sediments are presented by gray massive silt with sand. Shells or shell fragments of marine mollusks have been found in marine sediments. According to diatom analysis, these sediments are characterised by marine species such as *Diploneis pseudoovalis*, *Ehrenbergiulva granulosa*, *Paralia sulcata*, *Plagiogramma staurophorum*, *Mastogloia smithii*. Marine sediments are overlain by freshwater sediments – gyttia in the upper part of the cores. According to diatom analysis, by *Pseudostaurosira subsalina*, *Stauroforma exiguiiformis*, *Staurosira venter*, *Aulacoseira granulata*, *A. distans*, *Fragilaria construens*, *Cyclotella schumannii*, *C. rossii* were dominant in gyttia.

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In the lake №4 locating at 17 m above sea level (a.s.l.), silty gyttia of the Tapes transgression were found. Thus, the lake №4 was isolated from the sea at the beginning of the Holocene. However, it again connected with the sea during the Tapes transgression. In addition, the lower part of the Tapes sediments is presented by a chaotic mixture from sand, gyttia and plant remains. The formation of this sediments can be associated with tsunamis. It is detail considered in previously works (Tolstobrov et al., 2018; Nikolaeva et al., 2019).

Curve of relative sea level

On the basis of new lithological, micropaleontological and chronological data, a preliminary curve of relative sea level change was constructed (Fig.). However, the curve may be slightly corrected in the future.

Analysis of the sea-level (Fig.) shows that after the deglaciation of this area, the sea level was above 59 m relative to the current. During the Late Glacial and the beginning of the Holocene, there was a rapid regression of the coastline of the sea due to the uplift of the earth's surface. Rate of the regression was approximately 40 mm per year. About 11,500 cal years BP, the sea level fell below 17 m a.s.l. As a result of the Tapes transgression, which took place within the North Atlantic, the lake №4 connected with the sea. During the Tapes transgression, the rise of the sea coastline was more than 5 meters in the study area. At the maximum of the Tapes transgression, the sea coastline located slightly below the 21 m a.s.l. After 7300 cal years BP, a gradual regression of the coastline of the sea began at an average rate of about 2-3 mm/year.

4. Conclusions

Environments of the formation of bottom sediments were established as a result of the study of lake basins. Based on new data, a preliminary sea-level curve for the Teriberka area on the Barents Sea coast was constructed. It shows that sea level fell rapidly at a rate of about 40 mm per year during the Late Glacial and early Holocene. About 11,500 cal years BP, the sea level fell below 17 m and then rose by more than 5 meters during the Tapes transgression (10,000–7,600 cal years BP). After 7300 cal years BP, a gradual regression of the sea coastline occurred at an average rate of about 2–3 mm per year.

Acknowledgements

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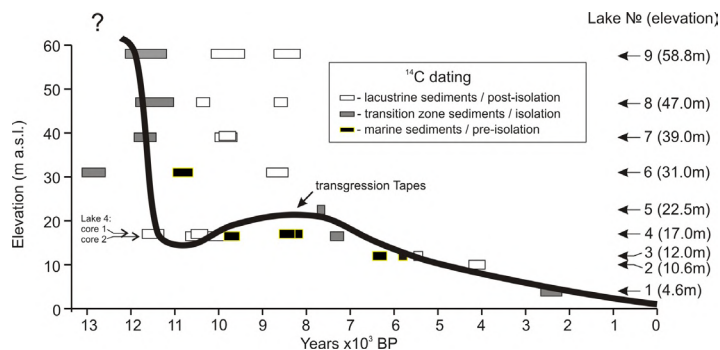


Fig. Preliminary sea-level curve for the Teriberka area based on dated isolation contacts in investigated lake basins. The curve refers to calibrated years.

Conflict of interest

The authors declare no conflict of interest.

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Environment of bottom sediments formation from the Lake Dedovo in the Voronya River valley (Kola Peninsula), according to diatom analysis (preliminary data)

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ABSTRACT. The study presents preliminary results of the species composition and distribution of diatoms in the core of bottom sediments of the Lake Dedovo located in the Voronya River valley (Kola Peninsula). It was determined that sedimentation occurred in the periglacial basin during Late glacial. After there was a large basin that connected with the sea, but this basin was freshwater due to the large influx of melt water. The level of this basin was at the same elevation for a long time at the beginning of the Holocene. According to preliminary radiocarbon dating, the isolation of the lake depression from a large freshwater basin occurred at the end of the Early–beginning of Middle Holocene. Lake Dedovo develops as an independent basin with a diverse freshwater diatom flora after the isolation.

Keywords: diatoms, bottom lake sediments, Voronya River valley, Kola Peninsula

1. Introduction

As is known, the analysis of diatoms in cores of bottom sediments of lakes makes it possible to reconstruct the environment sedimentation. Previously, diatom analysis of bottom lake sediments was carried out in order to determine their genesis for sea-level change researches. Such works were carried out on the Barents Sea coast of the Kola region in the areas of the Dalnie Zelentsy (Snyder et al., 1997), Nikel (Corner et al., 1999), Polyarny (Corner et al., 2001), and in the inner part of the Kola region in the Tuloma River (Tolstobrov et al., 2015), Lotta River valleys (Tolstobrov, 2018), and etc. This study presents a new data on the diatom analysis of bottom sediments of Lake Dedovo, located at an altitude of 23.5 m above sea level (a.s.l.) in the Voronya River valley, the Kola Peninsula (Fig. 1A).

The purpose of this article is to reconstruct the environment of bottom sediments formation from the Lake Dedovo in the Voronya River valley according to diatom analysis data in the late and postglacial period.

2. Materials and methods

The materials were obtained during field research in 2018. The core of sediments of different facies was taken in summer from a catamaran, using a

piston corer with 54-mm diameter. The thickness of the exposed bottom sediments was 360 cm. Lithological description, photographic documentation and sampling of bottom lake sediment cores were carried out in the field. The preparation of slides for diatom analysis was carried out according to standard methods (Diatomovyye., 1974). The main attention is focused on the characteristics of diatom species in relation to their salinity. The taxonomic identification of diatoms was refined according to the Algaebase database (Guiry and Guiry, 2022). Geochronological control was carried out using preliminary radiocarbon data.

3. Results and discussion

3.1. Lithology of bottom sediments

Sediments were described from the bottom to top. Depths are given from the surface of the water in the lake (Fig. 1B):

780–660 cm– gray clay with a bluish tint, with layers of silt and fine-grained sand. A lens of gray sand occur at a depth 752–754 cm.

660–607 cm — thinly laminated silt and organic matter (gyttia). A layer of gray sand occur at the 654–652 cm. Amount of organic material increases at the 630–607 cm. Mottled textures occur at the 607–612 cm.

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607–592 cm — laminated silt and organic matter, the amount of silt increases. Lamination gradually disappears, and the amount of organic matter increases up the section. The transition to the overlying gyttja is gradual.

592–438 cm — gyttja with interlayers 5–7 cm thick, expressed by color change. The color of gyttja is brown to greenish brown.

438–420 cm — gyttja dark brown, structureless.

Legend: 1–gyttja; 2–clay; 3–silt; 4–sand; 5–lamination; 6–weak lamination; 7–sharp boundary; 8–gradual boundary; 9–radiocarbon dating.

3.2. Diatom analysis

Diatom analysis was carried out for 12 samples. A total of 205 taxa of diatoms were found.

According to the data of diatom analysis, no diatoms were found in clay from the basal part of the section (780–660 cm). Previously, we assumed that clays accumulated in the sea basin according to lithological data (Tolstobrova et al., 2019), however, diatom analysis did not confirm this. The absence of diatom valves probably indicates the accumulation of this interval under severe conditions of a periglacial basin.

In contrast to clay, a rich and diverse freshwater diatom flora was found in the thinly laminated silt and gyttja (660–607 cm). Indifferent species predominate (80–92%), the subordinate position belongs to halophobes and halophiles, which account for 5–18% and 0.2–3.5%, respectively. Species with unclear position belonging to salinity range from 2 to 7‰. The dominant species is the planktonic species *Aulacoseira subarctica* (O. Müll.) Haworth. Planktonic species *A. ambigua* (Grun.) Simons. and fouling species *Stauroforma exiguiiformis* (Lange-Bert.) Flower, Jones et Round, *Staurosira venter* (Ehrb.) Kobayasi, *Tabellaria flocculosa* (Roth) Kütz were identified as subdominants. Other species are represented in smaller numbers and are very diverse. The similar composition of the diatom flora was identified at the 607–592 cm. This composition of the diatom flora corresponds to the freshwater environment of sedimentation. We assume that there was large basin connected with the sea after the glacier retreat. However, this basin was freshwater due to the large influx of meltwaters and small width and depth of the valley. According to the thickness of the laminated silt and gyttja and preliminary data of radiocarbon dating, the level of this basin was approximately at the same elevation for a long time (Fig. 1B). Later, as a result of the fall in the relative sea level, the level of this large basin also fell, and the studied lake was isolated. According to radiocarbon dating, the isolation of the Lake Dedovo was at the end of the Early – beginning of the Middle Holocene.

Freshwater diatom flora found in gyttja (592–438 cm). There is a change in the dominant species, while no significant changes in salinity have been identified. The ratio of species changes according to the pH of the environment towards oxidation. The planktonic species

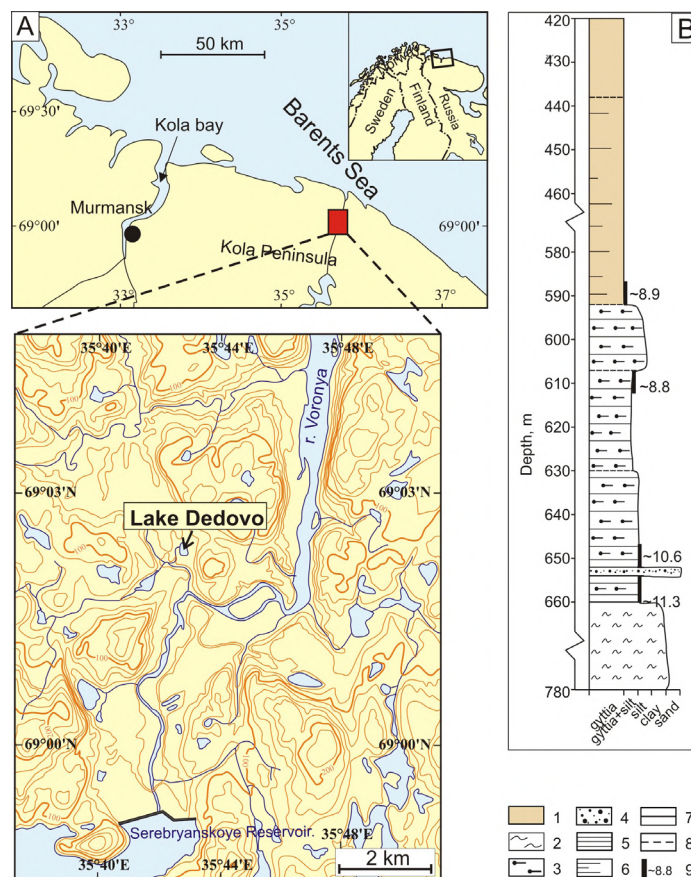


Fig.1. The location of the study area and section of bottom sediments of Lake Dedovo.

A. lirata (Ehrb.) R.Ross and the fouler *S. exiguiiformis* were identified as dominants here, the subdominant is *Pseudostaurosira brevistriata* (Grun.) Williams et Round.

4. Conclusions

(1) The absence of diatoms at the initial stages of sedimentation in the bottom sediments of Lake Dedovo indicates the existence of a periglacial basin in this part of the valley in the late glacial period. (2) After the retreat of the glacier a basin was formed here, which was connected to the sea, but was freshwater due to the large influx of melted glacial waters. (3) The isolation of the Lake Dedovo depression from this large basin took place at the end of the Early – beginning of the Middle Holocene. After isolation the Lake Dedovo develops as an independent basin.

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Conflict of interest

The authors declare no conflicts of interest.

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Short communication

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Lithostratigraphy of the bottom sediments of Pskovsko-Chudskoe Lake in the proposed site of the Ice battle

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ABSTRACT. The Ice battle is one of the most famous battles in Russian history. However, there is still no clearly answer as to where the Ice battle took place. Paleogeographic reconstructions can help in finding the place of the battle. The study area is a section of the southern part of Pskovsko-Chudskoe Lake. The works were carried out in the vicinity of Samolva and Kobylie Gorodishche villages of Gdov district of Pskov region, in the Zhelchensky Bay of Pskovsko-Chudskoe Lake. The key methods in this work are bathymetric survey, bottom sediment sampling, and lithological analysis. Three main types of bottom sediments are distinguished: sands at the bottom part of core section, upper it overlain by a thick layer of peat, which covered by gyttja.

Keywords: Pskovsko-Chudskoe Lake, Ice battle, stratigraphy, bottom sediments, lithology

1. Introduction

The Ice battle took place on the ice of Pskovsko-Chudskoe Lake, one of the most famous battles in Russian history on April 5 (12), 1242, but the exact location of this event has not yet been established (Subetto et al., 2021).

“The last line” in the search for the place of the Ice battle was summed up by an expedition led by G. N. Karaev, who began work in 1958 (Karaev et al., 1976). In recent years, in connection with the anniversary of A. Nevsky, interest in the subject of the battle of the Ice has intensified: in 2020 works were conducted under the aegis of the Russian Military Historical Society (a bathymetric survey of the supposed site of the battle was carried out), and in 2021 the Underwater Research Center of the Russian Geographical Society organized the expedition “In the footsteps of the G.N. Karayev expedition”, within which a detailed survey of underwater relief with multibeam echo sounder was performed, and the bottom sediment was taken for reconstruction of the lake coastline position at the time of the battle. This article will describe the lithological composition of these columns of bottom sediments.

2. Materials and methods

The field work was carried out in May 2021, together with the expedition of the Underwater Research Center of the Russian Geographical Society. Bottom sediments were sampled from the platform at

several points near the Gorodets Island. A Russian peat corer with a sampler diameter of 5 cm and a length of 100 cm was used for sampling bottom sediments. The sampled columns were described, photographed and delivered to the laboratory.

3. Results and discussion

The works were carried out in the vicinity of the villages Samolva and Kobylie Gorodishche, Gdov district, Pskov region, in the Zhelchensky Bay of Lake Peipsi, to the south of the island of Gorodets. Core section 1 (2.6 m depth at the sampling point) and 17 (2.1 m depth at the sampling point) are the most informative of all the sampled material.

Columns of bottom sediments extracted from Pskovsko-Chudskoe Lake are a lithological sequence of medium-fine-grained sands (sometimes with rare inclusions of organics), on which a thick layer of dark brown woody lowland medium-decomposed peat lies, overlain by gyttja (the uppermost layer of gyttja is sandy). In some cases, the peat is overlain by sand with inclusions of organic admixtures.

Using the results of radiocarbon dating, the age of each of the stages of the lake's development will be established and it will be possible to calculate the speed at which the water level in the lake could hypothetically rise. Diatom and pollen analyses will also be performed, which will help to better understand both the nature of changes in the lake level and the evolution of the surrounding landscapes.

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4. Conclusions

Based on the lithological description it is possible to assume the stages of the lake development: (1) post-glacial period when there was a glacial lake and medium-fine-grained sand was deposited; (2) descent of the glacial lake and formation of a 2.7 m peatland - presumably, the climatic optimum of the Holocene. During the period of peatland formation, the water level in Pskovsko-Chudskoe Lake in the study area was much lower than the modern one. The duration of the subaerial stage (peatland) was prolonged; (3) the lacustrine period - water level rise and peat flooding occur, as evidenced by lake sediments deposited on top of peats. The change of sedimentation type from subaerial (peat) to aquatic (gyttja) indicates a change in the lake level regime, its rise; (4) the upper relatively thin layer of sediment - sandy gyttja - indicates a decrease in the lake level and its shallowing in the study area in relatively recent times (horizon thickness is low).

The results of the research complemented by radiocarbon, diatom, and pollen analyses will allow a new perspective on the problem of finding the supposed battle site.

Acknowledgments

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Preliminary results of diatom analysis of bottom sediments from Lake Maloe Miassovo (Chelubinsk Region, Russia)

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ABSTRACT. In this study the diatom results of analysis a 510 cm long continuous sediments core from Lake Maloe Miassovo (South Urals, Russia) are presented. The core was collected in July 2018 from central part of the lake from a depth of 7 m. Diatom analysis of samples revealed 38 taxa, belonging to 29 genera and 18 family. The analysis of the ecological structure of the diatom flora of the sediment core sample from the lake under study shows that it is dominated by the Holarctic representatives of benthic and fouling organisms giving preference to the alkaline environmental conditions, which is due to the shallowness of the lake. The prevalence of *Staurosira construens* Ehrenberg diatom in sediments have been established. Diatom diagram has been divided into two diatom zones on the basis on changing diatom abundances and taxa composition. Diatoms were found in low concentrations, or were absent in the lower part of the core of bottom sediments, which could be due to a lack of organic substances, as well as low air and water temperatures. The composition of diatom complexes almost unchanged in the upper part, but their concentration increases significantly.

Keywords: bottom sediments, climate, diatom algae, Lake Maloe Miassovo

1. Introduction

The bottom sediments of water bodies are among the best sources of retrospective climate data (Zinnatova et al., 2019). Diatoms, cladocera, and remains of plants are used as indicator groups in paleoecological studies (Frolova, 2017). Diatoms are seasonally common to abundant in lakes, streams, rivers, and water bodies. Because of their siliceous cell walls, diatoms are well preserved in lake sediments. Their presence, absence, abundance and community makeup provide a snapshot of historical environmental conditions and change (Edlund et al., 2009). Due to the large number of taxa, diatoms are good indicators of a variety of lake water conditions including salinity, pH, light availability, temperature and nutrient levels (Zinnatova et al., 2018). Diatoms are commonly used as palaeoindicators, but remain relatively poorly studied in the Chelubinsk region. The aim of this work was to study the taxonomic composition of diatom flora from the sediment core of the lake Maloe Miassovo. Our research on the species composition and ecological parameters of diatoms provide additional data for the regional databases and contributes to improving the accuracy of paleoecological reconstructions.

2. Materials and methods

Lake Maloe Miassovo (55°10'04" N; 60°21'08" E) is located in the eastern foothills of the Ural Mountains, partially adjacent to the Ilmen Nature Reserve. The lake is of tectonic origin, the channel connects with Lake Big Miassovo. The length of the lake is 9 km, width – 1.5 km, area – 12 km². The maximum depth is 7.5 m, the average is 4 m. The water of the lake is characterized by a high degree of transparency (up to 7 m).

A long core no. 2 from Lake Maloe Miassovo was collected in the deepest part of the lake (at the depth of 7 m.) in July 2018. A long core of 510 cm was obtained in the field conditions and divided into samples, step of cutting is 2 cm. All samples were processed by the standard methods using 37% hydrogen peroxide as an oxidant of the organic matter present in the samples, including 10% HCl treatment in order to remove calcium carbonate, followed by rinsing with distilled water (Battarbee, 1986). The slides were prepared with the help of high refracting Naphrax® resin (RI = 1.7). Diatoms were identified under a Zeiss Axio Lab. A1 microscope using oil immersion at an objective magnification of 100× (1.4 n.a.) with Nomarski differential interference contrast (DIC). The total

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number of valves was considered 100%. Dominant species were those, which accounted for 10% of the total amount or more; subdominants were species which accounted for 5–10%. Diatom identification and taxonomy was based mainly on the Russian and foreign publications (Krammer and Lange-Bertalot, 1986; 1991; Lange-Bertalot and Krammer, 1989; Kulikovskiy et al., 2016). The nomenclature was given according to the modern electronic database “AlgaeBase” (Guiry and Guiry, 2015). The diatom valves were counted up to a maximum of 300. The diatom percentage diagram was created using the Tilia program, version 2.0.41. The results were zoned using CONISS (constrained incremental sum of squares cluster-analysis) within Tilia program (Grimm, 2004).

3. Results and discussion

Diatom analysis of samples of the core revealed 38 taxa, belonging to 29 genera and 18 family. The genus *Staurosira* is characterized by the maximum number of species. The dominant species were *Staurosira construens* Ehrenberg (25.22 % of the total number of species), *Staurosira venter* (Ehrenberg) Cleve & Möller (15.05 %), *Pseudostaurosira brevistriata* (Grunow) D.M. Williams & Round (9,94 %). In addition, species of subdominants were identified, such as: *Staurosira construens* var. *triundulata* (Reichelt ex Hartz & Østrup) E.Y.Haworth & M.G.Kelly, *Stauroforma exiguiformis* (Lange-Bertalot) Flower, Jones, Round, *Amphora pediculus* (Kutzing) Grunow, *Planothidium joursacense* (Hérub.) Lange-Bert. The analysis of the ecological structure of the diatom flora of the sediment core sample from the lake under study shows that it is dominated by the Holarctic representatives of benthic and fouling organisms giving preference to the alkaline environmental conditions, which is due to the shallowness of the lake.

Using the cluster analysis, the entire core was divided into two zones based on the presence of diatom taxa and their relative number.

Zone -DZ I

Diatoms were found in low concentrations, or were absent in this zone, which could be due to a lack of organic substances, as well as low air and water temperatures. The number of species was low, the proportion of planktonic-benthic and benthic species was equal. Cosmopolitan diatoms were represented in large numbers and amounted to 59%, according to the biogeographic characteristics, which may indicate a warming of the climate and an increase in the warming of the reservoir. In this historical period, such small-cell fouling as: *Staurosira venter*, *Staurosira construens* dominated, indicating large areas of shallow water and the presence of macrophyte thickets. In relation to salinity, indifferents prevail, and in relation to pH, most of the species encountered prefer an alkaline habitat, however, there is a species, namely *Stauroforma exiguiformis*, which prefers slightly acidic environmental conditions.

Zone - DZ II

The composition of diatom complexes remains almost unchanged, but their concentration increases

significantly. The maximum species diversity and mass development of diatoms were noted in sample 156. Benthic diatoms predominate in this diatom zone, which indicates sufficient transparency of the water column and average depths. Species that prefer alkaline environmental conditions still dominate, but the proportion of acidophiles increases compared to the previous zone, which may indicate the presence of wetlands in the study area. Permanent dominants of the complex are *Staurosira venter*, *Staurosira construens*. An increase in these species in the studied interval indicates a significant watering. The dominance of cosmopolitan species is replaced by holarctic ones, due to such species as: *Cavinula scutelloides*, *Planothidium joursacense*, *Pseudostaurosira brevistriata*, etc.

4. Conclusions

Based on the results of diatom analysis of the bottom sediments of Lake Maloe Miassovo, it can be concluded that throughout history, the oligotrophic-mesotrophic status of trophic and alkaline environmental conditions, with signs of waterlogging, have been preserved in the reservoir. The analysis of the ecological groups of diatoms in relation to the habitat showed that during the period of accumulation of the studied thickness in the lake, benthic forms of diatoms that meet the conditions of a shallow, overgrown with aquatic vegetation of the lake dominated. It is worth noting that the improvement of the climatic situation affected the productivity of the ecosystem of the reservoir as a whole, which was reflected in an increase in the concentration of diatom flaps in the upper layers of the sediment column.

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Conflict of interest

The authors declare no conflict of interest.

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Paleoecological reconstruction of ecosystem of Lake Imandra (Russia, Murmansk region) based on diatom analysis of sediments

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ABSTRACT. This paper provides information about diatom assemblages in sediments of large arctic reservoir (Lake Imandra). The distribution of the taxonomic composition and structure of diatoms for several centuries has been studied. The periods and causes of changes in the state of the lake ecosystem are determined, and a conclusion about future trends is made. The data obtained can be used for monitoring the ecological state of the environment and water bodies.

Keywords: diatoms, sediments, paleolimnological reconstruction, Arctic, anthropogenic influence

1. Introduction

Lake Imandra is one of the largest Arctic water bodies with major socio-economic importance. The reservoir is used as a source of technical and drinking water supply, as well as for recreation, tourism and fishing. A number of industrial enterprises are located in the catchment area, including Kola nuclear power plant on a direct-flow cooling system, mining, metallurgical and chemical production. It is necessary to understand the long-term trends of ecosystem transformation for the rational management of natural water resources and water quality control, which can help minimize the negative consequences of anthropogenic impact. To solve these problems, diatom assemblages (DA) in sediments are studied, which are a sensitive and reliable indicator of environmental changes. Based on the study of DA, we assessed the changes in the state of the lake ecosystem over the past centuries, both before and after the start of intensive anthropogenic load.

2. Materials and methods

We used two sediment cores from the Bolshaya and Jokostrovskaya Imandra stretches (Bol.I and J.I) as materials for the study, 37 and 57 cm long, were divided into layers of 1 cm each. We prepared samples according to the standard method (Juze et al., 1949; Davydova, 1985), with some modifications developed at Institute of the North Industrial Ecology Problems (Sandimirov et al., 2019). After laboratory processing of samples, taxonomic identification of

diatoms to the lowest taxonomic-level was performed using a microscope "Motic BA 300". Further analysis included our calculation of the relative abundance (by percentage) of taxa in DA, identification of dominant and subdominant species and analysis of the environmental characteristics of the identified diatoms (Barinova et al., 2006). Taxonomic information was checked against the current, regularly updated global algae database (Guiry and Guiry, 2022). Our taxonomic data have been included in the patented database "Algae of the Euro-Arctic region" and in the herbarium of INEP (Borovichyov et al., 2018). Based on the data obtained, the saprobity and Shannon-Weaver species diversity indices, and pH value were determined. To interpret the obtained materials, we used data on sedimentation rates based on the distribution of radionuclides (^{210}Pb , ^{137}Cs) and on the chemical composition of sediments.

3. Results and discussion

DA in sediments were studied in the deepest conditions of two stretches (Bol.I and J.I) experiencing direct anthropogenic influence.

We have identified 275 diatom species belonging to 64 genera in the sediments of Bol.I stretch. Diatoms in the core mostly belong to typically freshwater, planktonic forms that prefer a close to neutral or slightly alkaline habitat. Mass species in almost all analyzed sediment layers are represented by the taxa *Pantocsekiella comensis*, *Aulacoseira pusilla*, *P. rossii*, *Cyclotella bodanica* var. *lemanica*, *P. schumannii* and *Tabellaria flocculosa*. Radically new subdominants

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A. islandica, *Stephanodiscus minutulus* and *Cyclostephanos dubius* appear only in the surface layer. Analysis of the distribution of diatoms, indicators of species diversity, pH and saprobity, as well as concentrations of chemical elements in sediments identified the stages of development of the Lake Imandra ecosystem and their periods. The studied sediments were accumulated for ca. 200 years. It shows the “pre-industrial” state of the ecosystem in the deepest layers. Changes in the state of the ecosystem coincided with the beginning of the development of industry in the catchment area of the lake (1910-1935) and with the modern stage, including the last decades. In the first case, there is no radical restructuring of DA, but the species diversity decreases and the number of species increases. In the second case, there is an appearance of new dominant groups, a trend towards an increase in pH and saprobity index, accompanied by an increase in concentrations of toxic and biogenic elements in sediments.

Studying the sediments of the J.I area, we found 262 taxa of diatoms belonging to 68 genera. Diatoms in the core, similar to the previous core, are mostly typically freshwater, planktonic forms living in a neutral or slightly alkaline environment. Mass species in analyzed sediment layers are represented by the taxa *P. comensis*, *A. pusilla*, *P. rossii*, *P. schumannii* and *Lindavia radiosa*, and the number of all these species decreases in the surface layers compared with deeper ones. In these layers, including the upper 9 cm, new dominants and subdominants *Aulacoseira islandica*, *S. minutulus*, *S. Alpinus*, *A. subarctica*, *Cyclostephanos dubius* and *T. flocculosa* appeared. The studied sediments were formed for ca. 300 years, showing the “pre-industrial” state of the ecosystem in the deepest layers. Abrupt changes in the state of the ecosystem in this area also coincide with the beginning of the development of industry (1915) and with the current stage, when the maximum increase in production capacity in the lake’s catchment area took place in the last 50-60 years. In the first transitional stage, there is also no radical restructuring of diatom complexes, but species diversity decreases, the ratio of dominant species changes, there is an increase in trophic level on the reservoir, expressed in an increase in the saprobity index and concentrations of biogenic elements, as well as concentrations of metals. In the second stage, there is a sharp change in the dominant groups of diatoms and the appearance of new species, an increase in pH and saprobity, and the achievement of maximum concentrations of toxic and biogenic elements in sediments.

4. Conclusions

1. Changes in the composition and structure of diatom complexes of both studied sites occurred during the development of industry, and the most significant transformations have been observed in the last half century.
2. Ecosystem in the central part of the Bolshaya Imandra is less transformed than in the Jokostrovskaya Imandra transit zone, where wastewater from

non-ferrous metallurgy and apatite industry enterprises enters. Radical changes in the Bolshaya Imandra have been observed only in recent decades, and new species are just emerging, but have not yet completely replaced the “natural” species.

3. Ecosystem transformations are continuing at the present time, and with the preservation (or increase) of the intake of biogenic and toxic compounds into the reservoir, the situation may approach that observed in previous studies (Vokueva and Denisov, 2020; 2021) in the area of direct impact of the non-ferrous metallurgy and apatite industries (Moncheguba and Belaya Bays).

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Conflict of interest

The authors declare no conflict of interest.

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Results of long-term measurements of particulate matter in Lake Baikal

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ABSTRACT. For the first time, data on average annual particle fluxes in Lake Baikal from the past 22 years are presented. Sampling was carried out using sediment traps, which were installed at a mooring in the deep part of the Southern Basin of the lake (depth 1366 m) from March 1999 to March 2021. The total annual fluxes of sedimentary material during this period varied from 11.5 g m⁻² y⁻¹ to 208 g m⁻² y⁻¹. The peaks of fluxes correspond to the years of massive blooms of diatoms. Average total annual fluxes generally increase in the second half of the study period (since 2010), simultaneously with a change of the dominant diatom genera. We assume that the recent climate warming is responsible for these developments.

Keywords: Lake Baikal, sediment traps, particulate matter, average total fluxes of particles, diatoms, climate warming, terrigenous material

1. Introduction

Over the last decades, significant climate changes have been recorded, which have a sincere impact on the environment of our planet.

The aim of this research is to study the variability of vertical fluxes and material composition of particles in Lake Baikal, using data of sediment trap measurements. Such a study is important for an understanding of processes of recent sedimentation under conditions of climate change.

2. Materials and methods

During 22 years from March 1999 to March 2021, the collection and analysis of sedimentary matter from different depths of the water column of the Southern Baikal was performed. The work was carried out near the Baikal Neutrino Telescope observatory (51°46.076' N 104°24.948' E) at a water depth of 1366 m by using a mooring with integrating cylindrical sediment traps (Vologina and Sturm, 2017). Details of the exposure data are given in Table. The sampled material was freeze-dried on an FD ALPHA instrument and weighed on an analytical balance OHAUS Pioneer. The total annual fluxes of particulate matter (TAF) were calculated in grams per square meter per year (g m⁻² y⁻¹). The qualitative composition of the sedimentary matter was determined in smear slides under a SK14

light microscope (PZO WARSZAWA, Poland) with a magnification of 100x and 400x. Preliminary data have been published in (Sturm et al., 2015).

3. Results and discussion

The description of smear slides indicates that the collected material contains biogenic and terrigenous particles. The biogenic part consists mainly of valves of diatom species of the genera *Aulacoseira*, *Synedra*, *Cyclotella* and amphipods (*Gammarus* genus). Additionally sponge spicules are also observed. Allochthonous biogenic material is represented by pollen particles. The terrigenous material consists mainly of mineral particles of clay size with a little content of silt.

TAF varied significantly during the observation period from 11.5 g m⁻² y⁻¹ (2006) to 208 g m⁻² y⁻¹ (2014), with an average value of 89.6 g m⁻² y⁻¹ (Fig.). Average TAF values from March 1999 to March 2010 amount 75.1 g m⁻² y⁻¹, and from March 2010 to March 2021 104 g m⁻² y⁻¹. Thus, the total amount of sedimentary matter that entered Baikal over the past 11 years has distinctly increased. It should be noted that values of the lowest traps (about 15 m above the lake floor) were not taken into account in the weight calculations, in order to exclude effects of sediment resuspension at the water/sediment interface, which took place in almost every year. For example, in 2004 TAF was 79.8 g m⁻² y⁻¹ at a

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Table. Details of the exposure of integrating sediment traps in Southern Baikal between 1999 and 2020.

Years	Dates	Exposure, days	Number of traps	Water depth, m
1999	11.03.1999–06.03.2000	361	15	100–1362
2000	09.03.2000–08.03.2001	364	15	100–1362
2001	09.03.2001–07.03.2002	363	14	100–1350
2002	08.03.2002–09.03.2003	366	14	100–1350
2003	11.03.2003–08.03.2004	363	14	100–1350
2004	11.03.2004–07.03.2005	361	18	50–1350
2005	08.03.2005–06.03.2006	363	18	50–1350
2006	12.03.2006–07.03.2007	360	18	50–1350
2007	11.03.2007–05.03.2008	360	18	30–1350
2008	09.03.2008–05.03.2009	361	18	30–1350
2009	08.03.2009–05.03.2010	361	17	50–1350
2010	14.03.2010–07.03.2011	358	10	100–1350
2011	09.03.2011–09.03.2012	366	10	100–1350
2012	11.03.2012–09.03.2013	363	10	100–1350
2013	10.03.2013–09.03.2014	364	10	100–1350
2014	11.03.2014–15.03.2015	369	10	100–1350
2015	07.03.2015–05.03.2016	364	10	100–1350
2016	07.03.2016–07.03.2017	365	10	107–1359
2017	08.03.2017–06.03.2018	363	10	100–1363
2018	08.03.2018–05.03.2019	362	10	100–1363
2019	06.03.2019–04.03.2020	364	10	100–1363
2020	06.03.2020–17.03.2021	376	10	100–1363

depth of 1350 m, while at depths from 50 to 1200 m this value did not exceed $44.6 \text{ g m}^{-2} \text{ y}^{-1}$. Obviously, the high TAF values were associated with the resuspension of bottom sediments by currents and the activities of aquatic organisms.

Peaks of TAF were observed in 2000, 2002, 2007, 2010, 2012, 2014, 2017 and 2020 (Fig.) and correspond to years mass blooms of diatoms. Diatoms of the genus *Aulacoseira* dominated in the sedimentary material sampled in 2000. *Aulacoseira* together with *Synedra* dominated in 2002 and 2007. Then, starting from 2010, species of the genus *Synedra* were the predominant diatoms (peaks recorded in 2010, 2012, 2014, 2017 and 2020; Fig.).

It is known that the abundance and biomass of diatoms vary in different years and seasons (Votintsev et al., 1975; Popovskaya, 1977; 2000; Jewson and Granin, 2014). This explains the significant fluctuations in TAF over the past 22 years. The literature describes the so-called “*Melosira* years”, when there was a significant increase in the bloom of species of the genus *Melosira* (now renamed as the genus *Aulacoseira*) (Kozhova, 1961; Kozhov, 1962; Antipova, 1963; Evstafyev et al., 2010). According to published data, 2000 was a “*Melosira* year” (Evstafyev et al., 2010; Jewson and Granin, 2014). This phenomenon was also recorded by us in the study of sedimentary matter taken by sediment traps from March 2000 to March 2001 (Vologina and

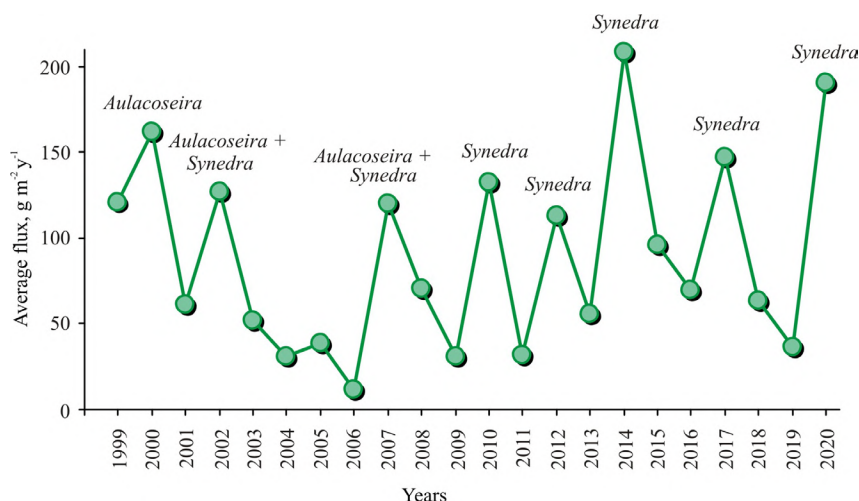


Fig. Total annual fluxes ($\text{g m}^{-2} \text{ y}^{-1}$) in Southern Baikal between March 1999 and March 2021. Predominant genera of diatoms are indicated.

Sturm, 2017). *Aulacoseira* was the predominant diatom genus in 2000. In 2002 and 2007 *Aulacoseira* and *Synedra* were the two main genera. The composition of diatoms in 2010, 2012, 2014, 2017 and 2020 was dominated by *Synedra* (Fig.). This period (2010–2021) was also associated with increased average TAF values.

It is noteworthy that species of the genus *Aulacoseira* are cold-loving diatoms (Votintsev et al., 1975; Chernyaeva et al., 2008). The dominance of the genus *Synedra*, observed in recent years, both in the water column and in the surface bottom sediments of Southern Baikal (Roberts et al., 2018; Vologina et al., 2019; Bondarenko et al., 2020; Vologina et al., 2020) is probably associated with climate warming. This is also revealed by an increased pelagic eutrophication of Southern Baikal (Izmest'eva et al., 2016). This conclusion is indirectly confirmed by results of the BDP-96 drill core from underwater Akademicheskyy Ridge of Lake Baikal, where the abundance peaks of *Synedra* are associated with warm isotopic stages (Khursevich et al., 2001).

4. Conclusions

Monitoring of vertical particle fluxes carried out over the past 22 years using sediment traps in South Baikal allows us to reach the following main conclusions. The total annual flux of particulate material that settled on the lake floor of Baikal varied significantly during the study period. Maximum TAF values occur in years with massive diatom blooms. Between 1999–2021 a change in the dominant species of diatom genera has been observed: *Aulacoseira* prevailed in 2000; *Aulacoseira* together with *Synedra* in 2002 and 2007; *Synedra* dominated since 2010 (2010, 2012, 2014, 2017, 2020). Simultaneously, the average TAF has increased over the past 11 years. This and the decrease of cold-adapted diatoms are believed to have been caused by climate warming during the last years.

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Conflict of interest

The authors declare no competing interest.

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Short communication

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Natural and anthropogenic impact on the biodiversity of malacofauna of the Caspian Sea

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ABSTRACT. Generation of biodiversity during the Neopleistocene and the Holocene was determined by the parameters of aquatic environment of basins (the sea-level mode, temperature, salinity), mainly reflecting climatic changes. The anthropogenic factor contributes essentially to the structure of the biodiversity. This paper aimed to show the impact of natural and anthropogenic factors on the generation of the mollusk's biodiversity. The material for research was the analysis of the long-term field works of the author on the coasts of the Caspian Sea and the studying of the core of sea boreholes. It is concluded that over the last 6 thousand years, invasive and acclimatized species made much more significant changes in biodiversity than those caused by natural factors. Natural ecosystems have undergone the anthropogenic transformation. Over the course of historical time, there has been not only fast change in biodiversity, but also irreversible change in aquatic ecosystems. The role of the anthropogenic factor on the species distribution in the basin became the major.

Keywords: Caspian Sea, mollusks, biodiversity, Pleistocene, Holocene, natural factors, anthropogenic impact

1. Introduction

Malacofauna is an important component of the Caspian Sea ecosystem. Mollusks are sensitive to changes in the physical, geographical and hydrological conditions of the basin and serve as an important indicator of changes in the natural environment. Generation of biodiversity during the Neopleistocene and the Holocene was determined by the parameters of aquatic environment of basins (the sea-level mode, temperature, salinity), mainly reflecting climatic changes. The anthropogenic factor contributes essentially to the structure of the biodiversity. This paper aimed is to show the impact of natural and anthropogenic factors on the generation of the mollusk's biodiversity.

2. Materials and methods

The material for research was the analysis of the long-term field works of the author on the coasts of the Caspian Sea and the studying of the core of sea boreholes. The main method is malakofaunistic, including the study of taxonomic composition, taphonomy, biostratigraphic distribution, historical development, phylogeny, mollusk biogeography.

3. Results and discussion

The composition of modern mollusks is the result of evolutionary processes in the Pleistocene fauna that occurred under conditions of climatic changes and transgressive-regressive rhythm of the Caspian Sea. In the recent (Neopleistocene and Holocene) history of the sea, the development of six transgressive basins was reconstructed: Baku, Urundzhik, Early Khazar, Late Khazar, Khvalynian and Novocaspian complicated in turn by stages, phases and oscillations. They are all separated by the epochs of regressive basins. Each basin had unique environment. For most of the Neopleistocene, the Caspian was a drainageless water body. The flow into the Pontian basins along the Manych Strait was observed there for 5 times. (Popov, 1983; Yanina, 2012). The inflow of the Black Sea waters into the Caspian Sea was not recorded. In the epochs of large transgressions, the Caspian area increased 2.5 times compared to the modern one, and the level increased to +50 m. During regressions, the Caspian level dropped to -100 m abs. The Caspian Sea was a brackish-water basin with relatively small fluctuations in salinity (no more than 6-7 ‰) during the Neopleistocene. As for temperature, cold and warm transgressions were released (Yanina, 2012; 2013). Malacofauna relates to

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the abundance of endemic cardiid and dreissenid bivalve species (of the genera *Didacna*, *Monodacna*, *Adacna*, *Hypanis* and *Dreissena*). Malakofaunistic analysis of the Neopleistocene sediments (Yanina, 2012) showed that despite the transgressive-regressive rhythm of the Caspian Sea of significant amplitude, the generic composition of mollusks remained unchanged.

In the Holocene, the marine species *Cerastoderma glaucum* is widely distributed. Malakofaunistic studies of the Holocene deposits of the Caspian region (Svitoch and Yanina, 1997; Yanina, 2012; Vande Velde et al., 2019) showed the first appearance of this species in the sediments of the Novocaspian transgression and its gradual spread and increase in abundance. There is no convincing evidence for the penetration of the species from the Black Sea into the Caspian Sea. There is no evidence of the functioning of the Manych Strait between the Pontus and the Caspian in the post-Khvalynian epoch. The author of the paper is inclined to assume that *C. glaucum* penetrated during the epoch of maximum of the Novochernomorsk transgression of Pontus when there was a sea bay inhabited by these mollusks in the West Manych Valley. A number of residual saline lakes existed in the Manych Depression. From the sea bay through the chain of lakes with the help of an ancient man (who used to eat these mollusks), this eurybiont species got into the Novocaspian basin. One way of its penetration is aquatic.

Thus, the penetration of a marine species into the Caspian was connected with an anthropogenic factor already in the first half of the Holocene. Its influence on the Caspian fauna was significant. All facies of the Novocaspian deposits of the Turali section (Dagestan coast) contain shells of this species (Vande Velde et al., 2019). Thus, the biodiversity structure of the Novocaspian basin has changed: there has been an increase in the number of taxa due to the biological invasion of the Mediterranean specie *C. glaucum*. Significant changes occurred in the quantitative distribution of taxa: a gradual increase in the number of *C. glaucum* and a decrease in Caspian endemics of the cardiid family.

The modern epoch is distinguished by the development of two more marine species - *Mytilaster lineatus* and *Abra segmentum*. The first was entered into the Caspian Sea by chance during the transfer of ships from the Black Sea basin during the Civil War at the beginning of the 20th century. It was firstly recorded in the Caspian in 1928 (Abdurakhmanov et al., 2002). Because of similarity with *Dreissena* in substrate requirements, the emergence of *Mytilaster* led to the extinction of *Dr. caspia* and the pushing of *Dr. andrusovi* into areas with reduced salinity not available to competitors. Mollusk *A. segmentum* was acclimatized in the Caspian in 1947 in order to improve the food supply of sturgeon fish. Currently, bottom biocenoses is often dominated by *A. segmentum*, *M. lineatus*, *C. glaucum* (Abdurakhmanov et al., 2002; Yanina, 2012; Vande Velde et al., 2019), all of which are of the Mediterranean origin.

4. Conclusions

The Holocene complexes, unlike Neopleistocene complexes, whose change over time is caused by a change in the conditions of the aquatic environment, reflect a change in the biotic conditions of the basin - the introduction of the Black Sea species. Invasive and acclimatizing species have made greater changes in the biodiversity patterns than were caused by natural factors. Obviously, as a result of evolutionary development from a small number of related species, Caspian autochthons became possessed the universal qualities but weak species specialization, which ensured stability and relative resistance of communities to changes in environmental factors, but made them uncompetitive for marine universes. Natural ecosystems have undergone anthropogenic transformation, and historical times have seen not only a rapid change in biodiversity, but also an irreversible change in aquatic ecosystems. Currently, the role of the anthropogenic factor has become the most important in the distribution of some mollusk species in the basin. The modern development of the Caspian malacofauna leading to an increase in the diversity of mollusks because of the emergence of new taxa leads to a biodiversity loss at the global level.

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Conflict of interest

The authors declare no conflict of interest.

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Ponto-Caspian basins development during MIS 5

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ABSTRACT. The aim of this paper is reconstruction and correlation of events within the Ponto-Caspian basin system, and the response of the systems to the global climatic changes during the MIS 5 epoch. The Pontian and Caspian basins belonged to different types of the water basins, and evolved differently in the Pleistocene responding in different ways to the climate changes. The study is based on the analysis and integration of the drilling material and data published by numerous investigators of the region who have been working on the paleogeography of the Ponto-Caspian region in the Late Pleistocene.

Keywords: Caspian Sea, Azov-Black Sea basins, Manych, MIS 5, sea level change, climate change, correlation

1. Introduction

The Ponto-Caspian is a system of intracontinental water bodies, different in their paleogeographic development. The Caspian Sea is an isolated basin, the Azov-Black Sea is a basin, which at certain periods connects with the ocean. The Manych Depression occasionally functioned as a passage between the Caspian and the Pontian basins. The development of the basins is influenced by multiple factors. This paper aims to reveal connections between the climate changes, as well as between sea level fluctuations in the Caspian and Pontian seas and the evolution of their environments. The paleogeographic analysis focuses on the time interval MIS 5 (Late Pleistocene). The interval covers global climatic events: Mikulino interglacial (MIS 5e) and beginning of the Valdai glacial epoch (MIS 5d-a).

2. Materials and methods

The study is based on the analysis and integration of the drilling material (from the Caspian Sea, Manych depression and the Black Sea) and published data. The laboratory studies included lithological and geotechnical analysis of the cores, floristic and faunal studies of the organic remains extracted from the cores. We summarize published and novel data on the transgressive and regressive events and climatic changes in order to reconstruct paleogeographical evolution of the region during the MIS 5 epoch. The recent decades are marked by a sharp increase in the amount of such publications, which indicates a growing

interest of the scientific community in the history of those intracontinental basins.

3. Results and discussion

Caspian Sea

In the Caspian region the Upper Pleistocene sedimentary series have been studied mostly within the limits of oil producing fields in the course of prospecting works. The exploratory boring to a depth of 90 m has been carried out in three areas in the Northern Caspian Sea. The obtained core was studied with lithological, faunistic, palynological, and geochronological methods (Yanina et al., 2018; Sorokin et al., 2017). There are two transgressions (stages) distinguished within the late Khazarian epoch – the Late Khazarian and the Hyrcanian. The level of Late Khazarian transgressive basin reached about minus 10 meters at its maximum (Yanina, 2013). The water was rather warm, as suggested by the composition of the mollusk assemblage dominated by *Didacna nalikvini* and *D. surachanica*, is corroborated by the *Corbicula fluminalis* in the freshened water. The salinity was higher than at present (10–12‰ in the Northern Caspian). The Hyrcanian transgressive stage was identified in the Caspian history by G. I. Popov (1967) on the base on the analysis of boreholes drilled in the northwest of the Caspian Lowland and the Manych valley. The position of G. I. Popov was subjected to a harsh criticism by many specialists, most of which rejected the idea of the Hyrcanian stage. Our drilling materials allowed to return to the problem (Yanina et al., 2014; 2018; Sorokin et al., 2017). We have identified the Caspian deposits corresponding to

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the Hyrcanian transgressive basin. The typical feature of its fauna is the joint occurrence of *Didacna subcatillus*, *D. cristata* and rare Late Khazarian mollusks. The basin was freshened and exceeded the late Khazarian basin in size. The pollen assemblages suggest a somewhat cooler and wetter climate (Yanina et al., 2014).

The late Khazarian transgressive epoch is attributed to the beginning of the Late Pleistocene. As has been shown by uranium series dating, the Late Khazarian transgressive stage corresponds to 127–122 ka BP, while the entire Late Khazarian epoch is dated at 127–76 ka BP (Shkatova, 2010). The continental deposits exposed in the Srednyaya Akhtuba section in the lower reaches of the Volga correspond to the Late Khazarian and Hyrcanian stages in the Caspian Sea evolution. Their age determined by the OSL (optically stimulated luminescence) technique corresponds to the entire MIS 5 stage (Yanina et al., 2017).

Pont

In the Pontian region the Upper Pleistocene sediments have been studied within the Tamanian area of shelf. The exploratory boring to a depth of 60 m has been carried out in the depth 26 m. The obtained core was studied with lithological, faunistic, and geochronological methods (Bezrodnykh et al., 2019). There is Karangatian marine basin distinguished. It developed as a result of the Mediterranean water inflow. Its deposits are widespread and the basin paleogeography has been studied in details. The Karangatian transgression exceeded the present-day sea level by 6–7 m, the water salinity reached up to 30 ‰. There are two stages distinguished in the transgression development – the Karangatian and Tarkhankutian, each of them characterized by faunal assemblages with different proportions of stenohaline and euryhaline groups of mollusks. Two phases are also noted in the Karangatian stage. The earlier (Tobechik) phase was marked by a wide distribution of species typical for the present days (*Cerastoderma glaucum*, *Abra ovata* and others). The sea level in the basin was below that of today. The second phase (Karangatian) was characterized by the dominance of the halophilic species including those that are currently absent from the basin (*Cardium tuberculatum*, et al.). A series of the U/Th dates obtained for the transgression fall within the period of 140–70 ka BP (Dinamika..., 2002). According to the OSL data, the earlier stage of the transgression developed around 131–120 ka BP, and the later one – around 120–100 ka BP (Kurbanov et al., 2019). The Tarkhankut stage deposits yielded faunal assemblage, that included Mediterranean mollusk fauna, barren of halophilic elements and dominated by *Cerastoderma glaucum* and *Abra ovata*. The entire basin was confined within the present-day outlines of the Black Sea coasts and the salinity did not exceed 14–15‰. There were some Caspian species – *Didacna cristata*, *D. subcatillus*, *D. ex gr. protracta*, in the Tarkhankut basin (Bezrodnykh et al., 2019).

Manych

The analysis of the Manych Strait functioning based on the Quaternary series studies plays an important part in correlating the events and

understanding the connection between the Caspian and Pontian basins. Judging from the stratigraphic position and malacofauna recovered from the Manych valley deposits, there was an ingressive bay there at beginning of the Late Pleistocene (the Karangatian transgression maximum) which penetrated as far east as the Caspian – Black Sea water divide (Popov, 1983; Kurbanov et al., 2018). The presence of the Karangatian fauna in its deposits (*Cerastoderma glaucum*, *Chione gallina*, *Chlamys glabra*, *Ostrea edulis*) suggests a rather high salinity in the central part of the bay (~18–20‰). The head of the bay was close to the Kalaus River mouth. A wide distribution of *Cerastoderma glaucum* and disappearance of more halophilic species indicates considerably freshened water (up to 10‰) (Popov, 1983). G. I. Popov (1983) identified two stages in the Karangatian Sea ingression. The earlier stage corresponded to the development of an inlet of the Late Khazarian basin. The 2nd stage of the ingression correlates with the Hyrcanian transgression with a bay deeply penetrating westward via the Eastern Manych valley. When the level of the Karangatian basin dropped and the ingressive inlet shrank, the Hyrcanian water penetrated into the strait bringing mollusks *Didacna cristata*, *D. parallella*, *D. subcatillus*, *Monodacna caspia*, *Dreissena polymorpha*. The faunal content of core on the Taman shelf indicates this event. The salinity in the strait was about 8–10‰. The Hyrcanian deposits in the central part of the Manych depression are dated using OSL at 107 ± 7 ka BP (Kurbanov et al., 2018). It supports the earlier conclusion about the Karangatian sea level lowering (Tarkhankut stage) and the inflow of the Hyrcanian water during the cooling at the transition from the Mikulino Interglacial to the Valdai glaciation.

4. Conclusions

The Pontian and Caspian basins belonged to different types of water basins and evolved differently in the Late Pleistocene. The interglacial epoch (MIS 5e) was marked by transgression in both basins in the Ponto-Caspian System, which could be attributed to different reasons. Marine transgression in the Pont resulted from the rise of the global sea level and the opening of the straits (as the sea level exceeded the strait threshold) between the Mediterranean and the Black Seas. The Caspian lake transgression resulted from the positive water balance of the basin. The marine transgression reached its highest level, while the Caspian transgressive basin stayed below present mean sea level.

During the transition to the glacial period (MIS 5d-a), the Mediterranean Sea level was unstable: its development was interrupted twice (MIS 5d and 5b) by the level drop below the Dardanelles Strait threshold. Those events also affected the Marmara Sea, where marine transgression developed in two stages. During the first stage (MIS 5c) the level exceeded the Bosphorus threshold, which led to the rise of the Black Sea level. In the Caspian Sea, the climatic conditions of the transitional period resulted in positive water balance, which caused transgressive evolution of the Caspian basin. The Caspian water flowing through the Manych

into the Pontian basin opened the Caspian-Pontian strait.

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Conflict of interest

The authors declare no conflict of interest.

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Reconstruction of vegetation and climate of the past of the central Caucasus for materials from the Tarskoe swamp



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ABSTRACT. The reconstruction of vegetation changes of foothill zone in the central part of the North Caucasus based on the data of the Tarskoe swamp is presented. The swamp is the largest in this region of the Caucasus and is the most promising peat paleo archive. It has been studied earlier, but the cores were poorly dated. The Tarskoe was re-drilled, the sediments were dated, and pollen and microcharcoal analysis were carried out. Twelve radiocarbon dates were obtained for the deposits, the age of the bottom sediments was about 4.6 cal. ka BP. Based on the data obtained, it was possible to establish that the bogging occurred against the background of more open landscapes, with a greater proportion of meadows than at present. Only after 4.4 cal ka BP broad-leaved forests become more closed, in their composition *Fagus* were dominant, with alternating admixture of *Carpinus*, *Ulmus* and *Alnus*. The increase of *Alnus* after Cyperaceae is most likely reflect local changes, since this tree species settled in the swamp at a late stage of its development. The dynamics of fire activity is interesting, it is most pronounced in the intervals between 4.4-3.3 cal. ka BP and than from 2.2 cal. ka BP until present. The frequency of fires is probably related not to climate, but to anthropogenic activities. In almost all cases, this coincides with the appearance of cultivated cereals pollen and with an increase in the diversity and quantity of grasses associated with humans (weeds). Thus, the obtained data for the first time give a possibility to construct a dated sequence of changes in the composition of broad-leaved forests of the belt of Caucasus piedmont and confirmed the appearance of cultivated cereals pollen about 4.3 cal. ka BP, which is probably associated with agriculture of the Maikop culture.

Keywords: North Caucasus, Holocene, pollen analysis, paleoecology, microcharcoal

1. Introduction

In the North Caucasus, very few Holocene natural archives have been studied, and we can't reconstruct vegetation history or assess the long-term influence of agriculture and pastoralism on mountain ecosystems.

The Tarskoe swamp is one of the most promising sites. It had been studied twice before 2019. The first study did not provide dating for the core (Neishtadt, 1955; 1957); at the second, the core did not contain the upper sediments, they might have been removed during peat harvesting (Knyazev et al., 1992). The new drilling in 2019 fixed these problems.

The Tarskoe swamp is one of the largest peat bogs in the mid of North Caucasus, it occupies about 20 ha in the basin between the Lesisty and Pastbishchny ranges (42°57'46"N, 44°43'32"E; 806 m a.s.l.). The climate is temperate continental with warm and very humid summer and medium cold, snowy winter. The

swamp is located to the low-mountain belt of broad-leaved forests dominated by *Fagus orientalis* Lipsky and *Carpinus betulus* L. with *Quercus robur* L., and an admixture of *Corylus avellana* L., *Ulmus glabra* Huds. and *Pyrus caucasica* Fed. Swamp vegetation is formed by *Carex* sp. and *Phragmites australis* (Cav.) Trin. ex. Stend with *Matteuccia struthiopteris* L. and *Sphagnum* sp., with thickets of *Alnus glutinosa* L. in some places. The swamp was drained for pasture and haymaking in the mid-20th century. Traces of drains are still visible. The new drilling was made between them in an undisturbed area.

2. Materials and methods

2.1. Sediment description

A 327 cm core was collected using a Russian corer with a 5 cm diameter, the Tarskoe core consists of 7 sections, 50 cm long each. The lithology of the core:

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0 – 276 cm: moss-herbs peat (*Sphagnum*, Bryidae, *Carex*, *Eriophorum*) with interlayer of total sphagnum peat from 140 cm to 153 cm.

276 – 290 cm: herbaceous decomposed peat

290 – 300 cm: clay with herbaceous detritus

300 – 315 cm: total sedge decomposed peat rich in mineral matter

315 – 327 cm: clay

2.2. Dating

The chronology is based on twelve ^{14}C dates (Table). No suitable terrestrial remains were found, so the main material was bulk. We use Bchron package in the R for the age model (Haslett and Parnell, 2008; R: The R Project for Statistical Computing). The average sedimentation rate is 12 years/cm.

2.3. Microcharcoal analysis

Microcharcoal analysis was made on pollen slides for the 78 samples of 6 ml volume, each sample containing one tablet of Lycopodium at 15853 spores. The diagram of the concentration of microcharcoal was made in the Tilia-Tilia Graph (Grimm, 2004) (Fig.).

3. Results

The objectives of the study determined subsampling from the core: sediments of the Bronze Age and of the turn of the Eras were studied in detail (each cm); the rest of the profile was subsampled with an interval of 10 cm. We counted ca. 500 terrestrial pollen in each of 78 samples and identified 185 palynological taxa. The bottom sample had an unrepresentative amount of pollen. Only terrestrial pollen (AP + NAP) were used for the main percentage calculations. For the *Cyperaceae*, aquatics, spores of mosses or pteridophytes percentage were calculated from the total sum. Local pollen zones (LPZs) were singled out by cluster analysis. The AP/NAP ratio indicates the predominance of forest vegetation. But large proportion of NAP (up to 65%) at the base of the sequence is more typical of semi-open landscapes.

LPZ1 (4.6-4.4 cal. ka BP) reflects the beginning of swamping; deciduous forests alternated with meadow there (Fig.). The predominance of *Pinus* pollen (up to 27%) is associated with an openness increase and long distance wind transport, rather than with real participation in the local forest. The composition of the forests was formed by *Fagus*, with *Carpinus*, *Corylus*, *Tilia*, a small amount of *Acer* and *Prunus*, in some places with wild *Vitis*. Vast open spaces are identified by the abundance of Asteraceae, Cichoriaceae and Poaceae, many Caryophyllaceae, Apiaceae, *Scabiosa*, *Centaurea jacea*. *Hippophae rhamnoides* L. are associated with forest edges. Weak human impact is suggested by the presence of *Arctium* and *Cardus*.

In LPZ2 (4.4-3.2 cal. ka BP), the decreasing *Pinus* and increasing *Fagus* (30-52%) mark this phase as start of reforestation. The value of *Tilia* falls, but *Carpinus*, *Alnus*, *Ulmus*, *Quercus*, *Betula* and *Fraxinus excelsior* L. rise; *Prunus*, *Pterocarya*, and *Juglans* are occasionally found. A lot of open and edge forest areas are identified by the *Hippophae* and *Spiraea*, even *Daphne* indicates lightening of the forest. *Artemisia* increases; Poaceae, Chenopodiaceae are constantly present; Cichoriaceae, Rosaceae, and Apiaceae have several peaks. An increase in pastoral pressure is suggested by *Plantago lanceolata* (max), *Rumex acetosa*, *Urtica* and *Cannabis*; Cerealia pollen appears frequently.

Starting from LPZ3 (3.2-2.6 cal. ka BP), the stage of the minerotrophic swamp ends and *Sphagnum* mosses appear, it becomes more favorable for *Alnus* along the swamp periphery. The forest becomes more closed: *Fagus* reaches 57%, *Carpinus* 15%, *Ulmus*, *Corylus* and *Vitis* increase, but *Quercus* decreases; *Picea*, *Prunus*, *Pterocarya*, *Juglans*, *Castanea* are common. The NAP composition has the same dominants, but the diversity decreases. The anthropogenic markers are *Plantago lanceolata*, *Urtica*, Brassicaceae, singly *Cerealia*.

In LPZ4 (2.6-2.1 cal. ka BP), *Fagus* predominates (37-52%), *Alnus* reaches 30%, especially in *Sphagnum* interlayer, but *Carpinus* gradually decreases, dark conifers disappear, and the diversity of broad-leaved trees declines. The NAP composition shows insignificant changes, only *Artemisia* and *Thalictrum* increase. *Plantago media*, *P. lanceolata*-type, and *Urtica*,

Table. Dating of Tarskoe swamp.

N	Deth (cm) mean	Lab nr. Ki	Age BP	Median Probability	Age BP 2 σ
1	25	19688	1320 +/- 30		653-707
2	50	19689	1920 +/- 40	1835	1730 - 1939
3	75	19690	1880 +/- 80	1795	1687 - 1993
4	100	19691	2160 +/- 70	2152	1992 - 2335
5	125	19692	2329 +/- 40	2346	2302 - 2469
6	150	19693	2340 +/- 40	2356	2305 - 2491
7	175	19694	2750 +/- 50	2844	2759 - 2954
8	200	19695	2930 +/- 40	3081	2960 - 3183
9	225	19696	2980 +/- 40	3155	3003 - 3252
10	250	19697	2730 +/- 50	2827	2753 - 2939
11	275	19698	3490 +/- 50	3761	3631 - 3896
12	300	19699	4010 +/- 80	4492	4243 - 4656

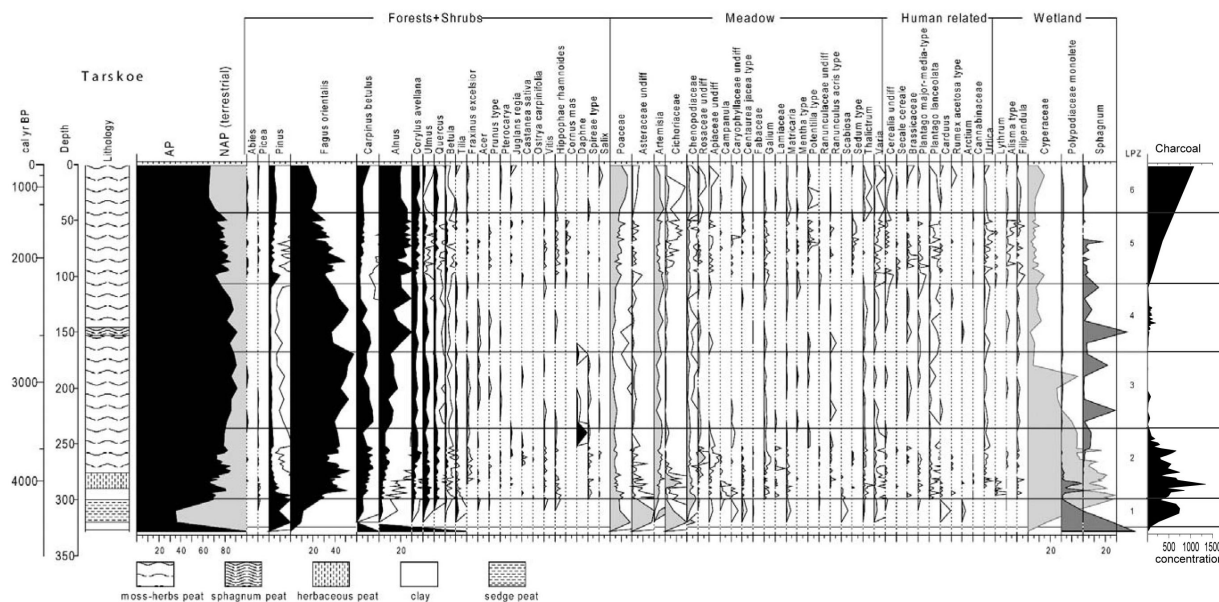


Fig. Pollen and microcharcoal diagram of Tarskoe swamp.

infrequent *Cerealia*, Brassicaceae, *Arctium* and *Rumex acetosa* are associated with humans.

LPZ5 (2.1-1.8 cal. ka BP) reflects the initial gradual increase in open areas. *Fagus* and *Carpinus* decrease, but shares of *Pinus*, *Betula*, dark coniferous, shrubs, and lianes rise. The Poaceae and diversity of meadow grasses increase; the *Secale* curve appears.

In LPZ6 (1.8 cal. ka BP – present), forest area continues decreasing or becomes sparser. *Fagus* noticeably reduces up to 15%, and then *Alnus* to 18%, with a slight rise in *Carpinus*, *Corylus*, and *Quercus*. Besides, value of distant pollen (*Pinus*, *Picea*, and *Abies*) increases. Open areas increase, as demonstrated by Poaceae (max), Cichoriaceae and Asteraceae. The pasture indicators include *Plantago lanceolata*, *Rumex acetosa*, and *Cardus*; and the agricultural ones - *Cerealia* and *Secale*.

The maximum concentration of microcharcoal in the section is noted in LPZ2(1500 units), the next highest value is observed in LPZ6 a little more than 1000 units. LPZ3 and LPZ4 has a very low concentration of microcharcoal.

4. Discussion and conclusions

At the beginning of the formation of the swamp about 4.6 cal. ka BP, the landscape of the foothills of the central part of the North Caucasus was semiopen, with a large proportion of meadows than today, perhaps this kind of landscape was under the influence of previous human activity, precisely of agriculture Maikop culture in the Bronze Age. This short-term episode is gradually replaced by broad-leaved forests, with a predominance of beech. Among the local transformations the replacement of Cyperaceae to *Alnus* and the appearance of *Sphagnum*, indicates a change in the type of water supply of the swamp. The greatest value of microcharcoal is most likely associated with anthropogenic activity, and is almost always synchronous with the appearance of cultivated cereals pollen. The first peak of microcharcoal (LPZ2) is

associated with an increase in diversity among a group of human-related grasses and appearance of cultivated cereals pollen about 4.3 cal. ka BP; the second peak (LPZ6) related with the increases of quantity of weeds and significantly increases the proportion of cultivated cereals pollen.

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Conflict of interest

The authors declare no conflict of interest.

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Aleika section – an “aftersound” of the Baltic Ice Lake at the Northern Coast of the Sambian Peninsula

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ABSTRACT. We present the new data concerning the traces of the Baltic Ice Lake in the northern coast of the Sambian Peninsula, Kaliningrad region, Russia, based upon the studies of the Aleika section (lithostratigraphy, radiocarbon dating, plant macrofossil, diatom and LOI analyses).

Keywords: Sambian Peninsula, Late Glacial, Baltic Ice Lake, chronology and palaeogeography

1. Introduction

The Baltic Ice Lake (BIL) was a huge proglacial water body that formed twice in front of the receding Scandinavian Ice Sheet during the deglaciation of the Baltic basin, the first, between 15 and 13 ka BP, and the second, during the Younger Dryas ice advance, ca. 12.8 ka BP (Björck, 2008). Though the configuration of both BIL stages was already reconstructed based upon various palaeoarchives in Scandinavian countries and Northern Europe (Uscinowicz and Zachowicz, 2003; Witkowski et al., 2017). Their position at the Sambian coast is still under discussion. In 2020-2022, we performed palaeogeographic studies of the northern coast of Sambian Peninsula, including lithostratigraphic observation of the sections, sampling for radiocarbon dating, LOI, diatom and plant macrofossil analyses, and DGPS survey. The Aleika section found during these studies provided new data on the BIL development and degradation in the Southeastern Baltic.

2. Materials and methods, results

The Aleika section (54.937051°N, 20.360373°E) is located on an abrasion cliff of the Baltic Sea 1.3 km west of the mouth of the Aleika River, within its catchment area, and exposes the remnant of a basin terrace; the total thickness of the exposed sediments is 2.4 m. The sedimentary succession includes 6 units (from bottom to top).

The Unit I (0.6-0.8 m a.s.l.) is composed of dark gray silt with rare inclusions of rock fragments (diamicton). An admixture of fine-grained sand is

observed at the top of the layer (0.8 m a.s.l.) marking the possible wash-out of the till surface; LOI values are low (3-4%). Rare finds of freshwater, mainly planktonic diatoms point to unfavorable environments for their growth and accumulation, such as in a large proglacial lake. The silt is overlain with brown peat with wood debris (Unit II, 0.8-0.95 m a.s.l.) with a sharp contact. This unit was radiocarbon-dated to 13800-13100 cal BP. Plant macrofossil analysis showed the swampy environment with transition from the waterlogged birch forest with green mosses to peat bog with sedges and Bryales; high LOI values (up to 73%) are typical for sediments of lowland peat bog development under stagnant water conditions. Extremely low concentrations of siliceous microalgae remains, i.e. diatom valves and chrysophyte cysts could result from moisture deficiency suggesting terrestrial or semi-terrestrial environments. Thus, after an abrupt regression of the large proglacial water body before 13800 BP that eroded the surface of the Unit I, the swamp formed on the drained surface.

Unit III (0.95-1.3 m a.s.l.) sharply overlies the peat layer and is composed of greenish gray gyttja with plant fragments in the upper part. The upper part of the Unit was radiocarbon-dated to 12800 cal BP. Plant macrofossil analysis inferred the shallow-lake environment with characteristic plant composition (pondgrass and hornweed), algae and Cladocera. Only benthic species were observed in the diatom record with the predominance of small-celled periphytic Fragilarieacea, which also suggests shallow-water low-energy environments. Increased concentrations of diatom valves, chrysophyte cysts and sponge spicules indicate favorable conditions for the development of

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aquatic biota and accumulation of microfossils. The LOI values increasing from 11-14% to 20-22% are characteristic for an isolated productive lake.

Unit IV (1.3-2.5 m a.s.l.) is composed of light-gray very plastic silt with small wood fragments and interlayers of fine-grained sand and silt. The radiocarbon date 12150 cal BP was obtained at the level of 2.2 m. Plant macrofossil analysis showed the presence of different algae. Very low abundances of all groups of siliceous microfossils (diatoms, chrysophytes, sponge spicules) characterize the environments of the proglacial lake where nutrients deficiency, low water transparency and temperature limited the productivity of aquatic biota, while high input of suspended particles “diluted” the microfossil concentrations in the sediments. LOI values, however, are rather high for the proglacial lake (4-9%), and may indicate the environment of an inlet or a lagoon.

Unit V (2.5-2.7 m a.s.l.) sharply overlies the Unit IV and is composed of peat with silt and sand admixture, radiocarbon dated to ~400 cal BP. Plant macrofossils are represented by sedges and green mosses. Poor preservation of diatoms, predominance of fragments of freshwater benthic taxa and high abundances of grass phytoliths speak for high-energy environments near the lake’s shore. Increased LOI values (10-16 %) also points to the shallow-water zone of a large basin. Unit VI (2.7-3.0 m a.s.l.) at the top of the section is composed of medium sand forming dunes at the subhorizontal terrace surface.

3. Discussion and conclusions

Our results revealed two phases of a large cold basin transgression in the coastal zone of the northern coast of the Sambian Peninsula in the Late Glacial: before 13.8 cal ka BP and ca 12.8-12.0 cal ka BP. The presence of sand in the upper part of the diamicton in the Aleika section indicates that the till (possibly, stadial one) exposed at the bottom of the section was apparently subject to erosion. Similar moraine outcrops with the washed-out upper part were encountered along the entire northern coast of the Sambian Peninsula. The age of the organogenic layers overlying the till suggests that washing-out could occur in the coastal zone of the Baltic Ice Lake during the first stage of its development dated to 14 cal ka BP (Björck, 2008), and the peat of the Unit II was formed after the first BIL regression. The

formation of the small lake and successive accumulation of gyttja 13.0-12.7 cal ka BP may reflect the increase of climate amelioration. The Younger Dryas cooling and expansion of the Scandinavian Ice Sheet caused another transgression of the BIL (Björck, 2008), and the area of the Aleika section was submerged again 12.7-12.0 cal ka BP.

After the second fast regression of the BIL at the end of Younger Dryas, this area of the northern Sambian coastal zone was the “stage” of alternating accumulation and erosion, which resulted in the huge gap in the sedimentary record until 400 cal years BP when the formation of peaty soil was interrupted by active aeolian processes that proceed by now.

The new data from the Aleika section enable tracing the evidences of the BIL along the northern coast of the Sambian Peninsula. This contradicts to the reconstructions of BIL coastal line 25-30 m below the present level of the Baltic (Uscinowicz and Zachowicz, 2003), and is in agreement with the reconstructions of L.Z. Gelumauskaite (2009) who suggested the complicated configuration of the BIL shoreline, with numerous inlet bays and moraine isles appeared during the transgressive phases, and small separate depressions formed after regressions.

Conflict of interest

The authors declare no conflict of interest.

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Proglacial lakes at the periphery of the southeastern LGM limit: configuration, chronology, degradation

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ABSTRACT. We present the new results concerning the chronology, distribution and dynamic of the proglacial LGM lakes in the valleys of the Severnaya Dvina and its largest tributaries Vaga and Sukhona. Our results refute the hypotheses of the extensive distribution of proglacial lakes and their flow to the south during the LGM. The lakes were local, with an unstable hydrodynamic regime and extended to a distance of 100-170 km from the ice sheet boundary.

Keywords: Southeastern periphery of the last glaciation, ice-dammed lakes, reversal runoff, Severnaya Dvina river basin

1. Introduction

During Late Pleistocene, Scandinavian ice sheet dammed the northward runoff of the rivers in the North and Northeast of the East European Plain, and proglacial lakes formed in the large river valleys. Accordingly, the southeastern lobe of the last Scandinavian ice sheet blocked the Severnaya Dvina River and its large tributaries that could lead to the formation of ice-dammed lakes.

First the idea of ice-dammed lake development in the Severnaya Dvina River valley and its large tributaries during the LGM was proposed by Krasnov (Krasnov, 1948) and then supported by Kvasov who reconstructed the Kotlaskoe proglacial lake in the Severnaya Dvina River valley, the Vaga proglacial lake in the Vaga River valley and the Sukhonskoe proglacial lake in the Sukhona River valley (Kvasov, 1975). The latter had the connection with the Kostromskoe proglacial lake and, consequently, with the system of the Upper Volga proglacial lakes (Kvasov, 1975).

In addition, Sukhona was not an individual river in the Late Pleistocene but consisted of the Eastern and Western Sukhona. Between these rivers, the Main Watershed of the East European Plain passed through the modern mouth of the Uftyuga River (Gosudarstvennaya..., 1989). The Western Sukhona flowed into Sukhonskoe Lake. During the advance of the Late Valdaian ice sheet, the Sukhonskoe Lake level rose to 145 m a.s.l. and had a runoff to the Kostromskoe proglacial lake (Kvasov, 1975). In the Holocene, the lake was drained, its erosion base level was lowered,

that led to the activation of river cutting. As a result, the Western Sukhona was intercepted, and a modern runoff was established (Gosudarstvennaya..., 1989). The modern lake Kubenskoye is a relic of the Sukhonskoe palaeolake (Kvasov, 1975).

At the beginning of the 21st century, a series of reconstructions of the huge damming of the Severnaya Dvina basin rivers was proposed for the last glacial maximum (LGM) with exceeded runoff threshold of 135 m a.s.l. and reverse runoff to the Caspian basin (Lavrov and Potapenko, 2005; Lyså et al., 2014; Larsen et al., 2013). According to these reconstructions, a glacial lobe penetrated far into the Vychegda and Vaga valleys which led to the formation of the proglacial lakes. Based on the DEM (Anisimov et al., 2016) with no geological verification, three proglacial lakes were reconstructed for the Sukhona valley: Verkhne-, Sredne- and Nizhnesukhonskoe. On the other hand, limited distribution of the LGM proglacial lakes was proposed in the very lower reaches of the Vychegda (Sidorchuk et al., 2001) or in the middle reaches of Severnaya Dvina (Zaretskaya et al., 2018; 2020a).

2. Materials and methods

We aimed to determine the time and limits of LGM proglacial lakes in the Severnaya Dvina basin. During fieldwork, we traced the proglacial lake deposits (varved clays) upstream from the LGM limits, performed lithostratigraphic studies of the sedimentary successions, sampling for instrumental dating and other analyses.

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3. Results and discussion

Lake Severodvinskoe. The deposits of this proglacial lake were identified and traced starting from the last ice sheet boundary (proximal facies) and continuing upstream (distal facies); the transition to the LGM alluvium was also traced (Zaretskaya et al., 2020b). Maximum thickness (5 m) was observed near the ice sheet boundary – these are continuous massive varved clays with large ice-wedge casts, underlain by sand. Upstream in the earlier studied Tolokonka section with a total thickness of 25–29 m (Maksimov et al., 2011; Lyså et al., 2014), several packs of varved clays interbedded with sand layers with ripple marks were found. The distal facies were observed 25 km downstream from the Severnaya Dvina and Vychegda confluence (75 km from the LGM ice limit). Dating shows that there were three stages of formation and drainage of the lake between 19 and 16 ka; that means that the Severodvinskoye Lake was a proglacial lake with unstable hydrodynamic regime.

Lake Vazhskoe. We traced the ice-dammed lake deposits in the Vaga valley from the lower reaches of the river where they first appear overlaying the LGM tills, to the place of their maximum development (up to 10 m thick) and then to the Verkhovazhie region (170 km from the LGM boundary) where their thickness decreases, and they eventually disappear (Zaretskaya et al., 2020b).

Despite the similarities of the Severodvinskoe and Vazhskoe proglacial lake deposits (sand interbeds with ripple marks, an increase in thickness close to the ice sheet boundary), there are also significant differences. First, in the upper part of varved clays there are organogenic layers, including plant detritus and even autochthonous peat with well-preserved plant remains. Second, we saw no ice-wedge casts in the varved clays, but it was found that they occur in the overlying alluvial sand. Third, the maximum thickness of clays in the Vaga sections is at least twice larger than in the Severnaya Dvina sections. And, fourth, in the Vaga valley, in the lower reaches of the river, there are “paired” packs of deposits of the glacial paragenetic series: the LGM till is continuously covered by the proglacial lake deposits. The organic-bearing varved clays were radiocarbon dated to 14.8–13.5 cal. ka BP, which means that the Vazhskoe Lake was drained no later than 14.8 ka BP. Apparently, the Vazhskoye and Severodvinskoye lakes existed synchronously, but the hydrodynamic regime in the Vazhskoye Lake was stable, the lake itself was larger and deeper and drained only once after the glacier retreat.

Lake Sukhonskoe. We studied the outcrops including the Sukhonskoe Lake deposits at the mouths of Tolshma, Tsareva, Staraya Totma and Gorodishna rivers (the Sukhona River tributaries). Glaciolacustrine sediments (varved-like clays less than 1 m thick) were found at altitudes of 110–118 m a.s.l., and the absolute height of their top limit decreases downstream of the modern Sukhona (Zaretskaya et al., 2021). The clays contain interbeds of sand with ripple marks, indicating the unstable hydrodynamic regime of the basin, as well

as numerous fragments of plant remains. Apparently, the Sukhonskoe Lake itself was formed in a periglacial depression. The “reverse” decrease of the glaciolacustrine deposits’ top limit probably indicates the existence of a glacial forebulge. The Main Watershed of the Russian Plain continued along it, crossing the Sukhona River near the mouth of the Uftyuga River. After the ice sheet degradation and the forebulge relaxation, the slope of the Western Sukhona was “skewed” and joined with the Eastern Sukhona, and the varved clays also received a “reverse” slope. Below the confluence of the Staraya Totma River, no LGM glaciolacustrine sediments were observed (Zaretskaya et al., 2021). The structure the Uftyuga River valley allows us to conclude that during the LGM there was no connection of the Sukhonskoe and Vazhskoe proglacial basins. Drilling in the zone of the proposed connection between the Kostromskoe and Sukhonskoe lakes disaffirmed the existence of a crossflow between them.

4. Conclusions

Our results refute the hypotheses of the extensive distribution of proglacial lakes and their flow to the south during the LGM. The lakes were local, with an unstable hydrodynamic regime and extended to a distance of 100–170 km from the ice sheet boundary.

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Conflict of interest

The authors declare no conflict of interest.

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Short communication

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Giant Late Pleistocene paleolake in Central Kamchatka depression (Kamchatka Peninsula, Russian Far East)

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ABSTRACT. A number of tephrochronologically correlated and dated sedimentary sections provide evidence for the existence of a giant lake filled the Central Kamchatka depression 30-11 thousand years ago. The lake extent bounded by CKD borders is estimated to be ~10 000 km². This estimate makes this lake comparable in size to the famous Late Pleistocene glacial Lake Missoula.

Keywords: Kamchatka, Late Pleistocene, periglacial lake, tephrochronology, active tectonics

1. Introduction

The evolution of Kamchatka landscapes remains poorly known even for the Late Pleistocene. Our recent tephrochronological studies based on the geochemical fingerprinting of volcanic glass particles and AMS 14C dating of host deposits provided a chronological lattice for the last 30 ka (Ponomareva et al., 2021). Dated lacustrine sediments revealed a period of simultaneous lacustrine deposition across the vast areas of the Central Kamchatka depression (CKD) that, together with fluvial topography pattern, indicates the existence of previously unknown giant lake within the CKD (Fig. 1).

2. Materials and methods

In recent years, we have examined a large number of outcrops of lacustrine sediments in the CKD. The sediments were sampled for grainsize, diatom, and pollen analyzes, tephra samples were collected for geochemical analysis. AMS 14C measurements were conducted by Beta Analytic Inc. (Miami) on the organic fraction of bulk lacustrine sediments consisting primarily of pollen, spores, and organic fossils. These dates permitted a Bayesian age-depth modelling for the KamPlen key section following the approach of

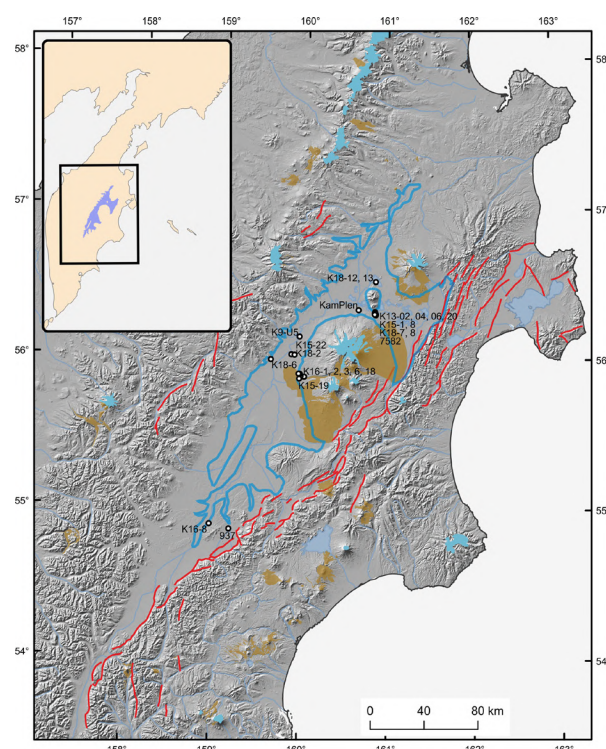


Fig.1. Studied sections (labelled white circles), and suggested extent of the CKD lake basin (blue outline in the figure and blue shade in the inset). Modern glaciers are shown in turquoise, Holocene volcanic deposits including debris fans are in light brown. Red lines are active faults.

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Blaauw and Christen (2011) with subsequent Bayesian modelling of the composite section (Fig. 2) in OxCal software (Bronk Ramsey, 2009). The geomorphologic setting of the studied sections was determined using the SRTM 1 arc-second and ArcticDEM digital elevation models supported by satellite imagery and UAV survey. Spatial data of the project as well as previously published maps and schemes have been collected in a geographic information system (GIS).

3. Results and discussion

All the studied sites are located below 160 m a.s.l., at heights 10-155 m above the CKD drain. There are no recent topographic barriers in most of the CKD, and the Last Glacial Maximum in Kamchatka is estimated to be no more than piedmont glaciers (Melekestsev et al., 1974). Therefore, the lake extent bounded by the CKD topography is estimated to be ~10 000 km². The age of studied deposits is 11-30 ka, whereas most of the sections are tied together by tephras in the time range between 19.3 ka (ZR-1) and 29.9 ka (Geys30).

Tens of thousands of years is a sufficient period for significant tectonic transformations of the topography. The eastern CKD border is the most active fault zone in Kamchatka with estimated horizontal slip rate of 13.3 mm/yr (Kozhurin and Zelenin, 2017). However, the listric main plane of this fault zone hampers accurate estimation of vertical displacement and its spatial distribution within the CKD. Accounting for these deformations, the CKD floor was partially higher in the past, so that the maximum lake depth was lower than the present day estimate of ~155 m.

The timing of the onset and drain of the Late Pleistocene lake indicates that climatic factor played a leading role in its evolution. However, tectonic deformations have been strongly affecting the topography of the CKD throughout the studied times, so that CKD drainage to Pacific Ocean prior the LGM was probably directed off the present-day drainage.

4. Conclusions

A number of tephrochronologically correlated and dated sedimentary sections provide evidence for the existence of a giant lake filled the Central Kamchatka depression in the Late Pleistocene, 30-11 thousand years ago. The lake extent bounded by CKD borders is estimated to be ~10 000 km². This preliminary size estimate makes this lake comparable in size to the famous Late Pleistocene glacial Lake Missoula. The reconstruction the lake emergence, evolution and drain requires an integrative study of the Late Pleistocene glaciation, volcanic accumulation and tectonic deformations.

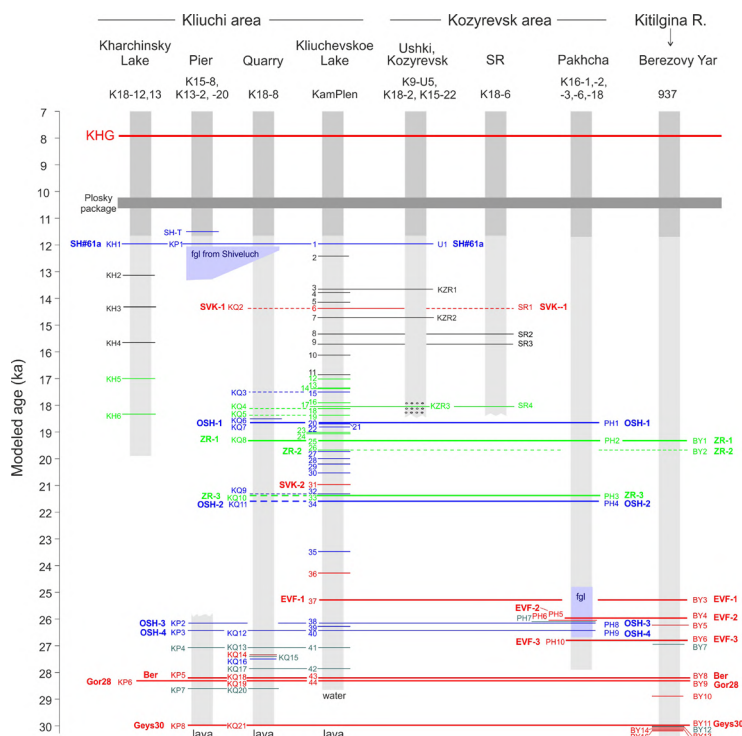


Fig.2. Tephrochronological age model of the mega-lake key sections (Ponomareva et al., 2021). Labels denote major marker tephra layers (bold) and site specific tephra IDs. Tephras are colour-coded according to their composition.

Acknowledgements

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Conflict of interest

The authors declare no conflict of interest.

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Reflection of climate events in deposits of Belarusian Lakes at the Middle-Late Holocene transition

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ABSTRACT. The analysis of the proxy archives from lake sediments made it possible to install the natural indicators the Holocene into three stages at 8200 and 4200 cal. yr. BP, the timing is consistent with that seen in the Greenland ice-core data. We studied proxy archives based on pollen-stratigraphic, sedimentological, radiocarbon and isotopic dates.

Keywords: Holocene, lacustrine deposits, pollen analysis, isotopes data

1. Introduction

According to the International Chronostratigraphic Chart the Holocene Epoch/Series is formally subdivided into three subseries/stages: the Greenlandian – a lowermost stage with a lower boundary dated at 11700 cal. yr. before present (B.P.) .P.; the Northgrippian – the Middle Holocene stage dated at 8200 cal. yr. B.P.; and the Meghalayan – an uppermost stage with a date of 4200 cal. yr. B.P. (Head and Gibbard, 2015; Walker et al., 2018). In the Chronostratigraphic chart of Belarus, the Holocene (H1) is also defined as an Epoch/Series within the Quaternary System/Period, but corresponds to the Lower Holocene subseries, which in turn characterized by Sudoble horizon (sd) or deposits of the unfinished Sudoble Interglacial (Zernitskaya et al., 2005). The Sudoble horizon (Lower Holocene) is represented by five layers (pollen-stratigraphy) that accumulated in the Holocene periods according to J. Mangerud et al. (1974). Nevertheless, in lacustrine sediments the natural markers that record specific climate events were identified at 8200 and 4200 cal. yr. B.P. (lithological, palynological, oxygen and carbon isotopes).

2. Materials and methods

The objects of the study were 10 lakes located in various regions of the country. Lakes Lozoviki (first in print as Lake Bezymiannoe, Makhnach et al., 2004), Naroch, Okono, Mezhyzhol and Teklits are situated in zone of the last glaciation, and Lakes Bobrovichskoye, Dvorischanskoye, Sergeevskoye, Staroje and Sydoble

are outside it. The geological material of the lake sediments was obtained employing coring through ice.

The samples were taken every 2–4 cm, volume 3 cm³ for pollen and isotope analysis. The isotope ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$) investigation were carried out at the Institute of Geology (Research and Production Center for Geology), Belarus (profiles Lozoviki, Naroch, Okono, Teklits, Sergeevskoye), at the Nature Research Centre, Lithuania (profile Staroje), and radiocarbon dating (^{14}C) – at the Institute of Geology (IGS, Minsk), at the Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine (Ki, Kyiv); AMS ^{14}C dates – at the Poznan Radiocarbon Laboratory (Poland) and at the Institute of Geography of the Russian Academy of Sciences (IGAN, Moscow) (Makhnach et al., 2004; 2009; Zernitskaya et al., 2010; 2019; Zernitskaya and Vlasov, 2019).

3. Results and discussion

Based on the results of loss-on-ignition survey, some main lithostratigraphic units have been identified in deposits of carbonate reservoirs. The lower part of the sections is represented by lake white-grey marls formed between 11700/11500–8300/8200 cal. yr. B.P. Above of level 8300/8200 cal. yr. B.P., marls give way silty marls, layers of yellowish grey carbonate sand can occur and organic matter (OM) increases. In the time range from 7900 to 4400/4000 cal. yr. B.P. the carbonate sapropels were formed, which has been overlain by organic or silts sapropels (Lakes Lozoviki, Naroch, Okono, Teklits and Sergeevskoye).

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In the North Greenland ice-cores, the event at 8200 cal. yr. B.P. was marked by negative shift in the oxygen isotope records, reflecting a cooling climate, which in various regions of Europe was characterized by either cold-dry winters and wet summer, or cold and snowy winter conditions (Veski et al., 2004; Ojala et al., 2008; Magny et al., 2012). The signal of this short-term cooling is clearly visible in the Belarusian isotope records as negative peaks of $\delta^{18}\text{O}$ between 8300–8000 cal. yr. B.P. At the same time, the quasi-synchronous shifts of $\delta^{13}\text{C}$ towards lower values were registered (8400–7900 cal. yr. B.P.), as well as increased OM (Lakes Lozoviki, Okono, Teklits and Sergeyevskoye) and/or mineral fraction in carbonate sediments (Lakes Staroye, Teklits and Bobrovichskoye). These data indicate an increase in humidity and an intensification of erosion processes leading to the influx of detrital material into the lakes. In the pollen spectra, the cold event was fixed by a drop in the pollen values of thermophilic trees (mainly *Ulmus* and *Corylus*) and an increase of content *Picea* in profiles lying in the north and in the center of the country and *Betula* and *Pinus* pollen – in the south region.

The event ca. 4200 cal. yr. B.P. was a new impulse to cooling and increasing humidity. During 4200–4000 cal. yr. B.P., the second post-optimal level of decrease of thermophilic trees pollen was established, simultaneously with the increase in the share of *Picea* pollen (profiles: Lozoviki, Naroch and Sergeyevskoye). The decrease in the isotopic composition of oxygen and carbon in the sediments of Lake Naroch began ca. 4200 cal. yr. B.P., and the minimum values were obtained in the range from 3400 to 2700 cal. yr. B.P. (Fig.), which was explained by the acceleration of water exchange due to cooling, reduced evaporation and increased precipitation (Zernitskaya et al., 2010).

4. Conclusions

A comparison of $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ ratios in bulk carbonates with pollen spectra and lithological compositions in lacustrine deposits of Belarus showed that the episodes of cooling in the Holocene were accompanied by an increase in humidity. These episodes often were coincided with the rise of lake levels, and were identified at 11400–11000, 9400–9000, 8200–7900, 7200–7000, 6400–6000, 5500–5200, 4200–4000, 3400–2700, 1500–1200 and ca. 800 and 500 cal. yr. B.P. (Zernitskaya and Vlasov, 2019).

Conflict of interest

The authors declare no conflict of interest.

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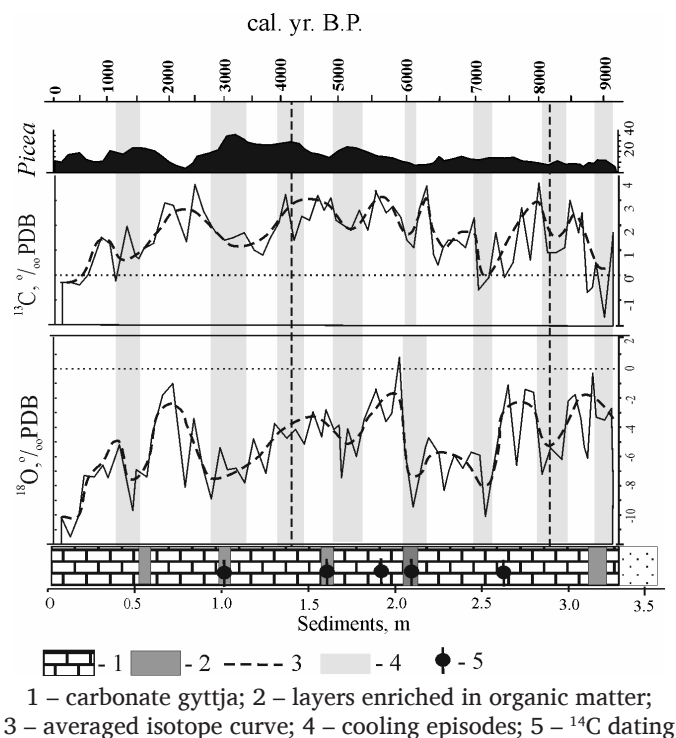


Fig. Correlation of isotope records and *Picea* pollen amount in Naroch lake carbonate sediments.

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Short communication

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Sediments of Lake Malye Chany as a Late Holocene paleoecological archive in the south of West Siberia (Russia)

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ABSTRACT. The paper presents the first results of multiproxy study of the sediment core from Lake Malye Chany. This lake is a part of the biggest drainless lake in Russian Lake Chany. The Kargat and Chulym Rivers flow into Malye Chany. The lake locates in the forest-steppe near the southern border of taiga zone which makes it a promising object for reconstructions of the vegetation shifts and other ecological changes of the past periods. The sediment core was investigated by sedimentological, pollen, chironomid, diatom, ostracod analyses. Based on pollen and chironomid data were made quantitative reconstructions of climate, vegetation cover and biodiversity. According to radiocarbon dates the upper 200 cm of the core covers the last ca. 3900 years. It was established that reconstructed time boundaries of climate, vegetation and ecological changes coincide according to various reconstruction approaches. At the beginning of its existence, Lake Malye Chany was a shallow saline lake with warm water; only after 2.4 thousand years BP the water level rose and the lake became fresh and the water colder. Then the water level and salinity changed, and only 1 thousand years BP the lake became deep again. The last 200 years recorded a slight warming of the water. Landscapes developed from very dry steppe to modern forest-steppe, about 2 thousand years ago there was a short-term cooling and spread of taiga elements. Last 200-300 years, there has been a steppification.

Keywords: Lake Malye Chany, south of West Siberia, multiproxy study, reconstructions

1. Introduction

Despite a number of lakes and peat-bogs studied in the south of West Siberia palaeoclimatological and palaeoecological tendencies are underinvestigated. Small lakes in Siberia are the most promising for climate and environmental reconstructions because their sediments record mostly local signals of the climate, vegetation and ecological changes. The lakes accumulate different kinds of organic matter formed inside them and transported from their catchment, including pollen, diatoms, chironomids etc which allow realization of multiproxy approach and complex reconstructions. Our research team includes scientists from Novosibirsk and several other national and foreign institutions studying

lakes in Siberia and Central Asia. Here we present first results of multiproxy study of Lakes Malye Chany.

2. Materials and methods

Objects and the study area. Malye Chany (54.55220° N, 77.99580° E) is a freshwater lake located in Novosibirsk region, with a surface area about 200 km², mean water depth of 1.4 m and salinity of 0.8 g/L. Lake Malye Chany lies at 106 m a.s.l. and is a part of the saline Lake Chany system, the biggest drainless lake in Russian. The Kargat and Chulym Rivers flow into Malye Chany. The lake locates near the southern border of the Baraba forest-steppe which is a temperate-

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climate ecotone and habitat type, where birch groves are inter-spersed with swamps and meadow steppes. In the north, the forest-steppe borders the southern taiga. Modern vegetation around Lake Malye Chany is presented by typical forest-steppe, steppe meadows and grasslands communities. Along the lake's shores grow aquatic plants such as *Typha* sp., *Potamogeton* sp., *Scirpus* sp. The climate of Baraba is continental; the annual temperature amplitudes are around 38 °C. Mean July temperatures are 18.3 °C, mean January temperatures -19.7 °C, annual precipitation level is about 400 mm.

The 3.6-meter-long sediment core of Malye Chany was investigated by sedimentological, pollen (99 samples), chironomid (17 samples), diatom (35 samples), ostracod, and petromagnetic analyses. Pollen and chironomid analyses data were used to reconstruct quantitative characteristics of climate (annual precipitation and temperature), vegetation cover (biomization) and biodiversity. Three radiocarbon dates were used to create the age-depth model according to that the upper 200 cm of the core covers the last ca. 3900 years.

3. Results and discussion

According to the sedimentological data, the lake sediments have thickness of 290 cm and there are two distinct lacustrine layers: one (290–190 cm) consisting of terrigenous material (sands) and another one (190–0 cm) considerably organic and authigenic (carbonates). As rivers Chulym and Kargat flow into Malye Chany we assume that the lower layer of terrigenous material (290-190 cm, border is about 3.8 ka BP) was formed under conditions of a low water level in the lake, when the river delta moved deeper and the sand brought by the rivers was deposited in the center of the lake. In the organic (sapropel) layer we can distinguish two stages of sedimentation: the shallow stage (3.8-2.6 ka BP) and the deep stage (2.6-0 ka BP). Salinization of the lake began at the end of the sand accumulation stage (after 3.7 ka BP), which may be related to a decrease in freshwater inflow due to decreased precipitation and/or river runoff. Gradual desalinization and eutrophication of the lake began after 3.3 ka BP, which suggests a constant inflow of river water during this period.

The ostracod analysis data indicate that up to 3.5 ka BP the water in the lake was brackish and well

heated. Then, up to 2.4 ka BP, the water was colder and salinity decreased. At the beginning of the deep water stage there was a drop in water level, the water became warmer, and the salinity of the water varied. After 1.1 ka BP, the water level rose again and the water became colder. Last 200 years are characterized by a slight warming of the water (Khazin et al., 2016).

The pollen data and the results of biomization were used to reconstruct plant communities development in the Lake Malye Chany area. In the period between 4.2 and 3.2 ka BP steppe communities with a large proportion of desert components dominated around the lake, the climate was warm and dry, there were probably intensive soil erosion processes and frequent fires, as evidenced by very high concentrations of chlamydospores *Glomus* and charcoal particles. After 3.2 ka BP, steppe also dominated, but desert components decreased, and macrophytes (water plants) began to grow along the lake shores. The climate was probably warm and humid. After 2 ka BP the area was covered by forest-steppe and the climate remained quite humid, but became colder. According to biomization data, in the period of 1.8-1.5 ka BP there was a short spread of taiga and a probable cooling. In the last 200 years, there is a slight increase in the role of steppe elements and a decrease in taiga elements, which may indicate the process of steppification associated with increased anthropogenic pressure.

The time boundaries of changes in reconstructed by different methods sedimentation conditions and environmental changes are well correlated or coincide.

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Conflict of interest

The authors declare no conflict of interest.

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