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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 km^2, water volume 295 km^3, 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,

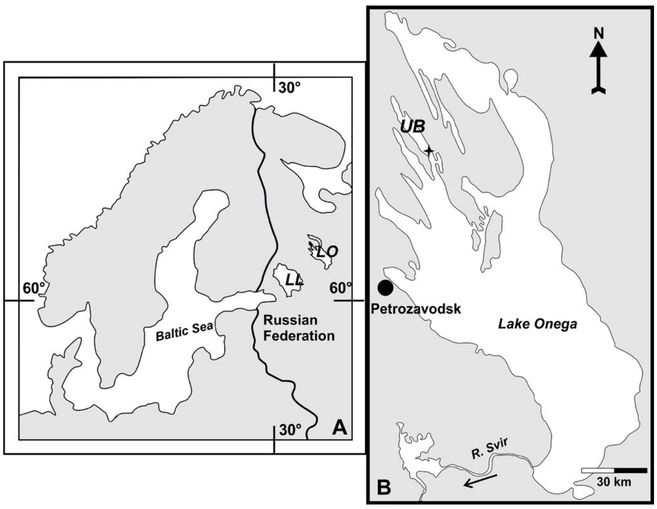

Fig.1. Location map of: A) Lake Onega (= LO; LL = Lake Ladoga), B) the study site (UB = Unitskaya Bay, star indicates the coring site)

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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 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 mln, cysts to >20 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. Eearlier 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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