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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 at., 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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