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TRIP TO LADOGA

HISTORY OF LAKE LADOGA AND ITS CONNECTION WITH THE BALTIC SEA

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The problem of the history of Lake Ladoga and the formation of the Neva River still remains controversial in many respects. The fundamental generalizations available at the moment by the authors (History of Ladoga, Onega ..., 1990; Evolution of Natural ..., 1993; Kvasov, 1975; Davydova et al., 1994; Subetto et al., 1998; The First International ..., 1996) leave a number of important issues that require further scientific study and solution. The main of these are the time of the origin of the river and the direction of flow from Ladoga to the formation of the Neva River.

The depression of the Lake Ladoga began to fill with water as the glacier of the Last Valdai glaciation collapsed and melted. According to studies (Saarnisto, Saarinen, 2001), devoted to the problem of deglaciation of the Ladoga and Onega Lake's basins using varvochronological, radiocarbon and paleomagnetic analyzes of varved clay, it was proved that Lake Ladoga was free of ice in the interval 14000-12500 calendar years (11800-10300 ^{14}C years ago) (Fig. 1).

Within the basin of Lake Ladoga, there was a deep-water, cold, oligotrophic periglacial water reservoir (Figure 2), *which was the easternmost part of the Baltic Ice Lake* (Davydova et al., 1998; Kvasov, 1975; Subetto et al., 1998), where during 2000 years formed a thick stratum of limnio-glacial varved clays (Subetto, 2002).

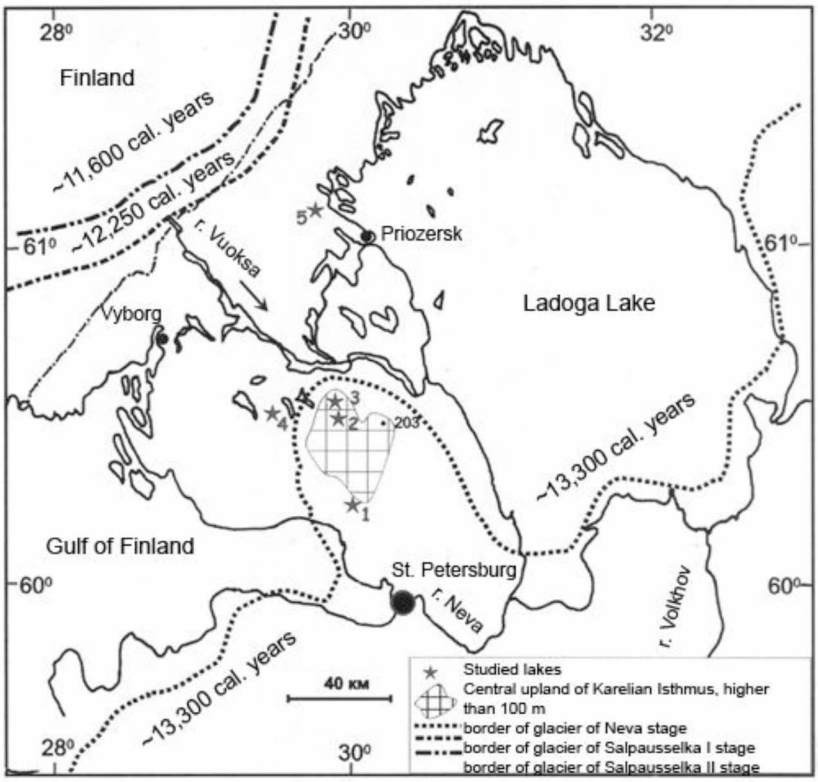
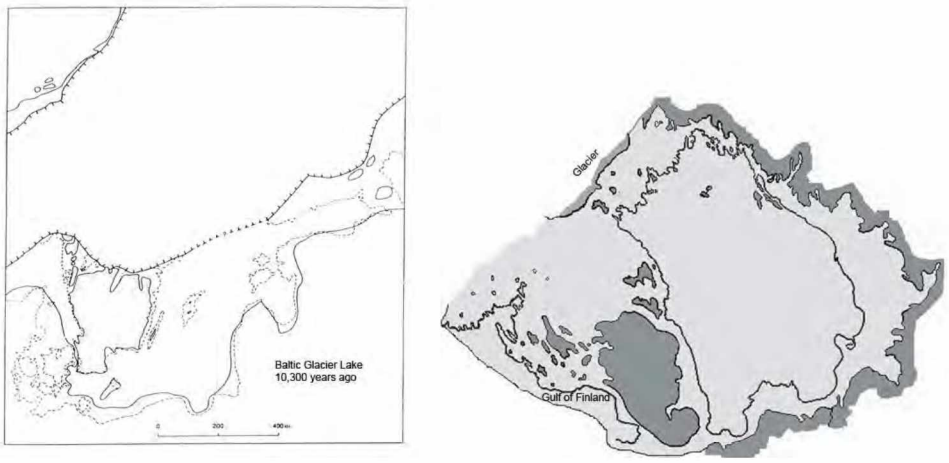


Fig. 1. Stages of deglaciation of Lake Ladoga.

A characteristic feature of laminated clays is their distinct graded bedding layering. In the sections of varved clays, as already indicated, alternating layers of two genera are observed:

clayey, comparatively thin and colored in darker tones, and coarser, aleuritic or sandy high power and light colored.



A) B)

Fig. 2. A) The position of the edge of the glacier and the adjacent Baltic Ice Lake (BIL) 10300 ^{14}C years ago or 11500 calendar years ago before its descent after the retreat of the edge of the glacier from the mt.Billingen in the Central Sweden. The dashed line shows the current position of the coastline of the Baltic Sea (Björck, 1994). B) Ladoga Lake was part of a large preglacial lake (BIL). The water level marks reached 50-60 m. The northern part of the Karelian Isthmus was flooded.

The first ones are called winter layers, the latter ones are called summer layers. Banded clays were formed from a glacial turbidity - a product of erosion of moraine, brought by streams of melt water into the periglacial water reservoir (Fig. 3).

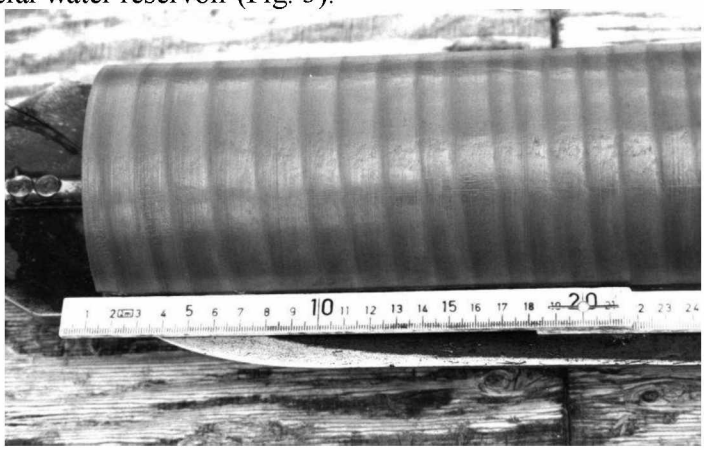


Fig. 3. Photo of varved clays formed in the conditions of a glacial lake. One layer corresponds to 1 year.

The sedimentation of a larger clastic material in the spring-summer period to the bottom of the lake, and the thinner material, suspended in the autumn-winter season, led to the formation of laminated (varved) clays. In the conditions of the cold, sharply continental climate of the late glaciers, the productivity of the lake and terrestrial ecosystems was low, which was reflected in the very low content of organic matter in banded clays. The powerful thickness of the lacustrine-glacial deposits of the BIL covers almost the entire bottom of the Ladoga Lake and their thickness reaches 20-30 m (Subetto et al, 1990). Deposits of the Baltic Ice Lake are also found in the sections of the bottom sediments of many lakes located in the northern lowland part of the Karelian Isthmus (Sevastyanov et al., 1997; Subetto et al, 1999, 2002).

Above the cut of the varved clays, the layers gradually subside until they disappear completely: the banded-layered clays are replaced by microlayered and homogeneous clays (Fig. 4).

This facial transition from one type of clay to another was associated with the gradual degradation of the glacier, the retreat of its edge from the lake catchment and, accordingly, with

the decrease in the arrival of clastic material and the precipitation of a predominantly suspended matter.

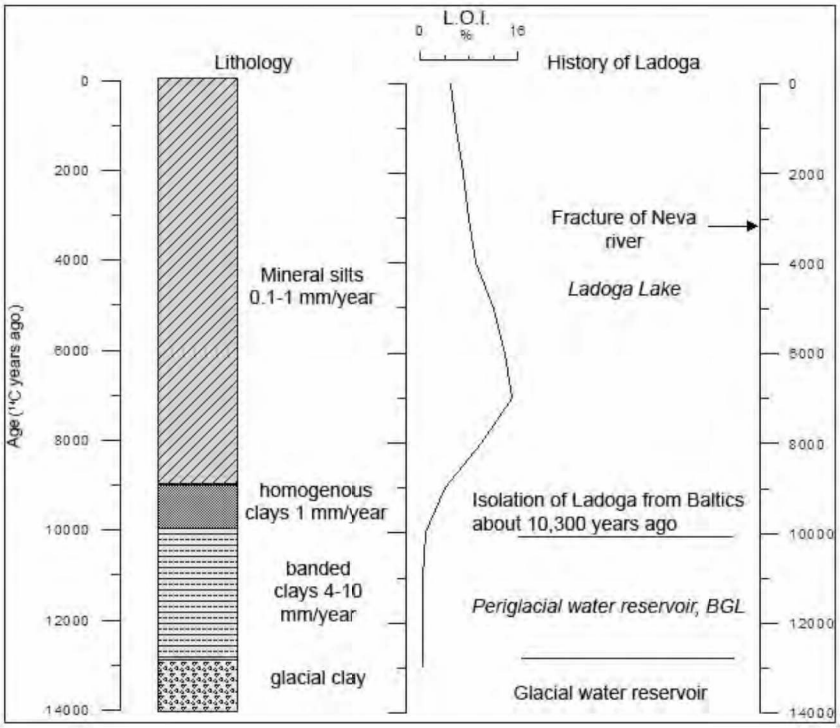


Fig. 4. General section of bottom sediments of the Ladoga Lake and paleogeographic reconstruction (Subetto, 2002)

The change in the structure of the sediments of the Ladoga Lake in time from glacial deposits (glacial clay) to limno-glacial (varved clays) and to lake sediments (homogeneous clays and silts) is shown. L.O.I. - loss on ignition of samples of bottom sediments, an index of change in the content of organic matter, which in turn is an indicator of the bioproductivity of the reservoir and changes in the temperature regime. The maximum content of organic matter in bottom sediments correlates with the optimum of the Holocene.

According to existing ideas, *the last reduction of the Baltic Ice Sheet took place unevenly*, as well as the subsequent isostatic uplift of the territory. It is believed that about 10,300 ^{14}C years ago in the area of present-day of mt. Billingen in Central Sweden (Figure 2), *the collapse of the glacial lobe led to the open of the straits, a sharp lowering of the sink threshold and a drop in the level of the BIL*, which caused the opening of a huge area from the Baltic Sea to the White Sea, adjacent to the edge of the ice sheet. *The lowering of the BIL was catastrophic and short-lived.* In the basin of the Baltic Sea waters of the world ocean penetrate, forming the salt-water conditions of the stage of the Yoldia Sea (Fig. 5). *From that moment the Ladoga Lake was isolated from the Baltic.*

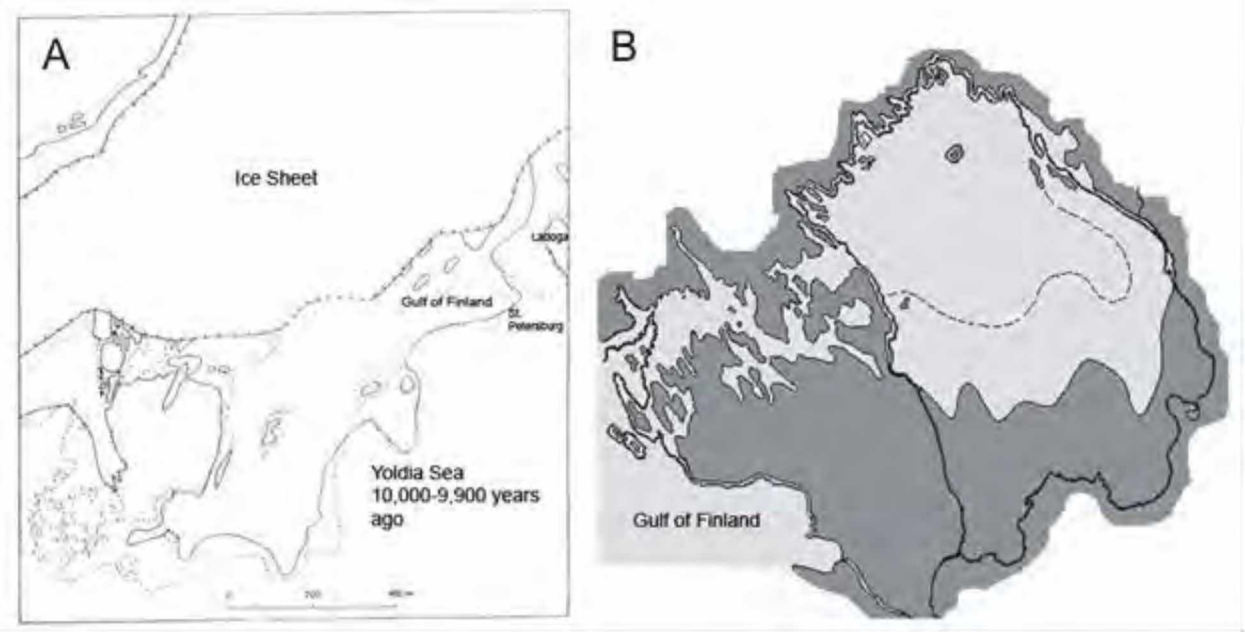


Fig. 5. A) The position of the edge of the glacier and the outlines of the Yoldia Sea, connected with the Ocean through the straits in Central Sweden (Björck, 1994). B) Ladoga Lake was connected with the Yoldia Sea in the northern part of the Karelian Isthmus. The dashed line shows the southern boundary of Ladoga Lake in the Yoldia stage.

The decrease in the level of the BIL was accompanied by strong processes of denudation and erosion of exposed parts of the bottom, as a result of which in the sections of the bottom sediments of most lakes in the northern part of the Karelian Isthmus there is a sandy layer at the contact of clays and overlying silt or a sharp boundary between them, indicating a break in sedimentation. In the structure of the sediments of lakes located within the Karelian Isthmus - the Hejnioki Strait, connecting the Ladoga Lake and the Baltic Sea, sand interlayers up to 0.5 m thick are found (Sevastyanov et al., 2001, Subetto et al. 2002), overlapping banded clays. Above, sand interlayers overlap with organomineral lake sediments (sapropels) and peat.

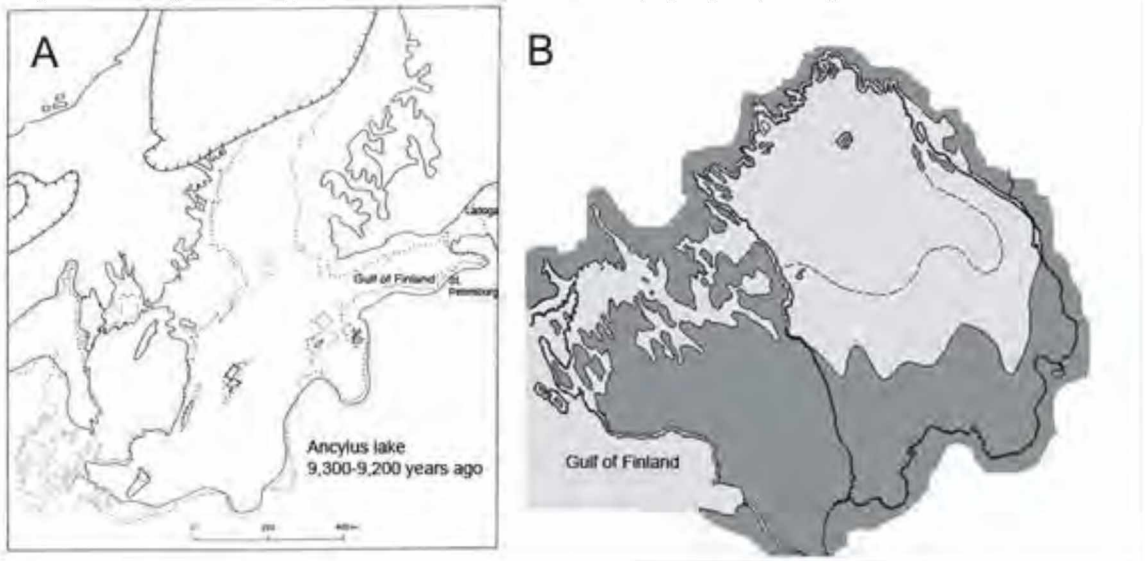


Fig. 6. A) Ancylus stage of the Baltic Sea during the maximum of the transgression associated with the closure of the straits in Central Sweden due to the isostatic uplift of areas liberated from ice (Björck, 1994). B) Ladoga Lake was connected with the Baltic through the strait in the northern part of the Karelian Isthmus where the water level reached 25 m.

In the early Holocene (10,300-9,500 years ago), due to the significant warming of the climate in the Northern Hemisphere, the rapid destruction of the Baltic Ice Sheet, the descent of the Baltic Ice Lake, and as a result the isolation of the Ladoga Lake, a lake-glacial type of sedimentation by lake type (Fig. 4) took place. Characteristic low-power gray homogeneous clays (0.2-0.8 m) are formed.

In the second half of the Preboreal time, the level of the Ladoga Lake rose to a height of 18 to 20 m. This was a consequence of the Ancylus Lake transgression of the Baltic (Fig. 6) of about 9200 years ago, which led to a sprinkling of the runoff from the Ladoga Lake and, as a consequence, a rise in the water level in the lake (Fig. 7). During the maximum of the Ancylus transgression, the southern shallow water of the Ladoga Lake was flooded to modern isobaths of the order of 20 m (Figure 6).

About 9,500 / 9,000 years ago, approximately at the boundary of the Preboreal and Boreal, in the basin of Ladoga Lake, lacustrine sediments (silt, silty clay) begin to accumulate (Fig. 4). Due to the fact that the water area of the lake in the Holocene has been repeatedly reduced, the full and most powerful sections of the silt are observed in the northern deep-water region. In the process of sedimentation, the role of organic matter of autochthonous origin increases. In silts there is an increase in the content of organic matter in comparison with clays.

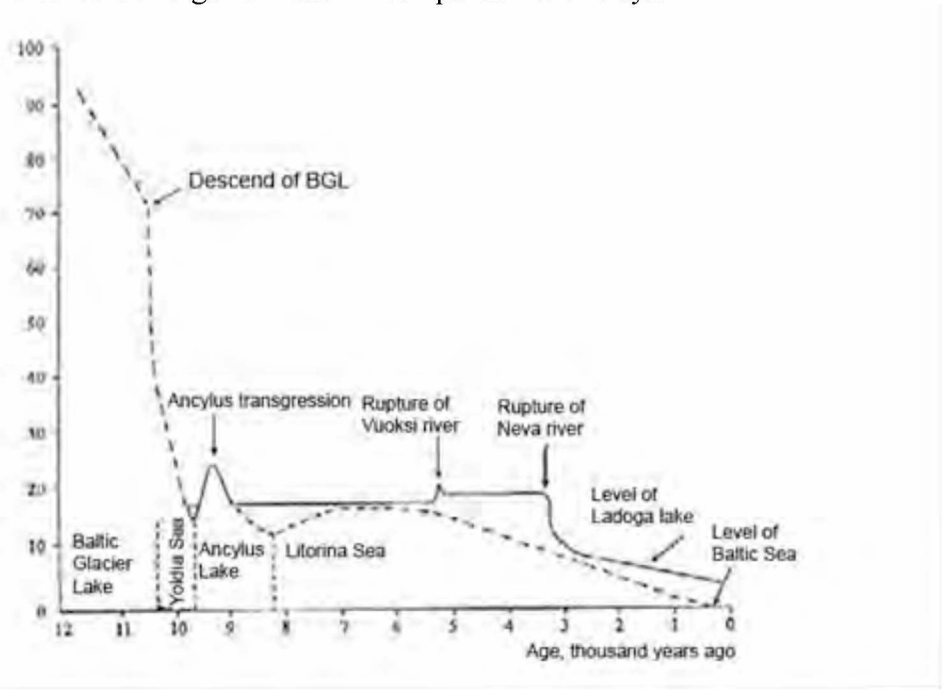


Fig. 7. Reconstruction of changes in the levels of Ladoga Lake and the Baltic Sea in the late and postglacial periods (after Saarnisto, Grönland, 1996).

At the turn of the Preboreal and Boreal about 9000 years ago the level of Ladoga again decreases due to the regression of the Baltic to the markings below the current situation, which is recorded from the study of bottom sediments in the shallow southern part of the lake (History of Ladoga, Onega ..., 1990, Subetto et al., 1998, Subetto et al., 1999).

There is a dismemberment of the Ladoga and the Baltic, the Hejnioki Strait dries up, and many lakes of the Karelian Isthmus are separated, in which organogenic silt is formed, and peat bogs are formed in the mouths of rivers. According to different authors, the radiocarbon age of peat bogs is 7870 ± 110 years ago in the area of Pitkyaranta, 7970 ± 260 and 7960 ± 230 years ago at the mouth of the Ojat River; 7110 ± 170 BP on the river Vjun, 6900 ± 70 years ago on the Olonka River (Koshechkin, Ekman, 1993; Subetto et al., 1999; Abramova et al., 1967).

The stream from Ladoga at that time was directed through the system of the Vuoksa river-lake system to the Vyborg Bay, and the drainage threshold from Ladoga was in the area of the modern Veschevo settlement (Finnish name of Hejnioki) at an altitude of 15.4 m above sea level.

The most interesting and debatable period in the history of Ladoga is the period of the last 5000 years. This stage, which received the name "Ladoga transgression" in the literature, corresponds with the interval 5000 - 3000 years ago (Fig. 8). The reasons for this transgression are treated ambiguously. M. Saarnisto (Saarnisto, 1970) saw the main reason in the leading isostatic uplift of the earth's crust on the northern coast of the Finnish and Baltic Gulf, as a result of which the flow of water from the Saimaa system of lakes to the Gulf of Finland stopped. As a result of skew, a new threshold of flow arose through the marginal ridge of the Salpausselkia-I moraine from the city of Imatra to the river system. Vuoksi, which at that time flowed from Lake Ladoga to the Baltic. The waters of the largest Saimaa lake system of Finland, which is sprung by the moraine ridges of Salpausselkä, according to his idea, broke into Ladoga, sharply increasing the input part of the lake's water balance.

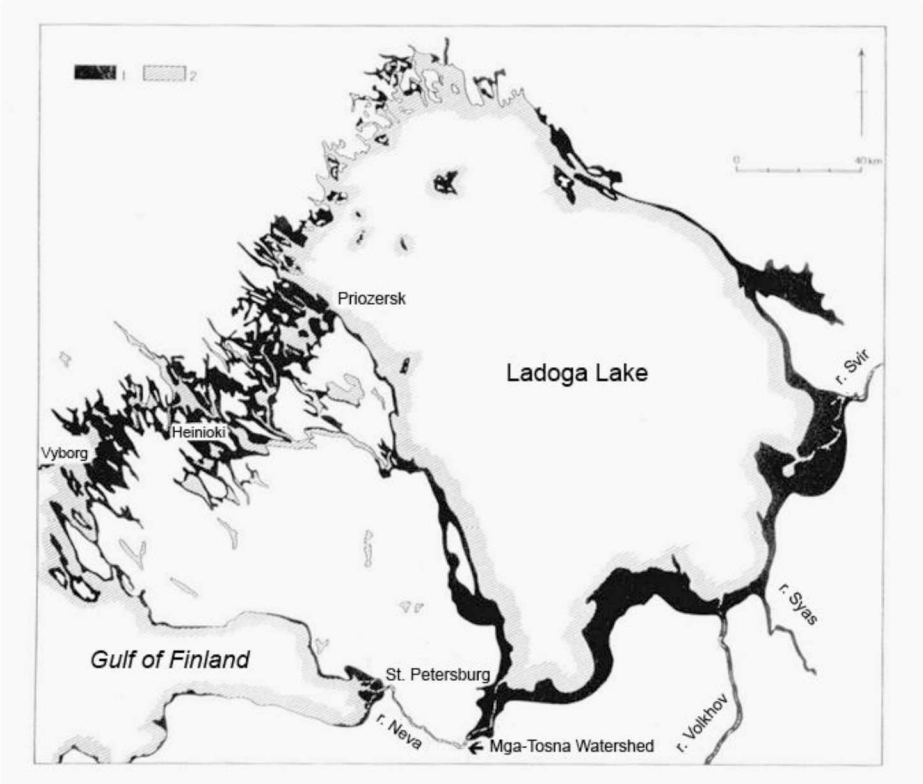


Fig. 8. The map showing the modern outlines of the Ladoga Lake (oblique shading (2) and during the maximum of the Ladoga transgression (black color (1)) before the rupture of the Neva river (after Saarnisto, Grönland, 1996).

The result of the development of the Ladoga transgression, as commonly believed, was the overflow of Ladoga through the Mga-Tosna watershed and the formation of the Neva River. Most researchers, beginning with G. de Geer, Yu. Ailio, E. Huppä, who later were referred to by D.D. Kvasov (Kvasov, 1975) believed that the Neva channel between Ladoga and the Baltic was formed mainly as a result of the glacioisostatic uplift of the northern Ladoga and the skewing of the Ladoga basin, as a result of which the lake's waters flooded its southern part and infiltrated the valley of the river Old Mga, which flowed into Ladoga. They reached the height of the Mga-Tosna watershed represented by a ridge (about 18 m), composed of morainic loam), washed it and carried out the descent of the Ladoga waters along the valley of the river Old Tosna, which had previously flowed into the Gulf of Finland. At the same time, the lower parts of the valleys were widened and deepened by a drainage from Ladoga (Fig. 8).

The time of the maximum of the Ladoga transgression and the beginning of the formation of the Neva River have different datings for different authors. Yu. Ailio (Ailio, 1915) and S.A. Yakovlev (1926) believed that the Neva arose in the period 4,500-4,000 years ago. Later K.K. Markov et al. (1934) pointed to the short-lived nature of the Ladoga transgression, which fit into

part of the subboreal period. O.M. Znamenskaya et al. (1970) dated its age 2000 years ago, and D.D. Kvassov (1975) considered it in the interval of 2300 - 1200 years ago. According to M. Saarnisto and T. Grönlund (Saarnisto, Grönlund, 1996) the Neva arose around 3100 years ago.

In the study of D.B. Malakhovsky et al. (1993) there are new conclusions about the time of the Ladoga transgression and the formation of the Neva River, which are specified by dating of the differently aged terraces and roofs of peat bogs underlying the sediments of the transgression in the section "Nevsky Forest Park" (3000-2800 years ago) and overlapping them in the section " Nevsky Bridge-head " (2400 years ago). Thus, on the basis of these data, in a short period of time about 400 years, the level of Ladoga has decreased from 18 m to 5-6 m, which is quite realistic, given that the southern watershed of the lake was composed of loose sedimentary rocks, while the northern one - Heinik - was composed of crystalline.

With the isostatic uplift of the northern part of the Karelian Isthmus, drying and swamping of the Heinik Strait occurred, as a system of lake-river ducts on the line Priozersk-Veschevo-Vyborg.

In the course of the regression of the Ancylus Lake and the continuing uplift and distortion of the northern part of the Ladoga Basin, the level of Ladoga and the Baltic has become equal. It was at this time that a new drain from the north broke out of the Saimaa system of lakes and its bifurcation arose. Partly this flow went along the old valley of the Hejnioki Strait to the Gulf of Finland, and part of the runoff continued to the Baltic Sea. A large volume of sediment transported along the western shore of Lake Ladoga and contributed to the blockage of the flow from Lake Ladoga along the valley of the Sukhodolskoye Lake (former Lake Suvanto). The powerful sandy shorelines of the subboreal time, 17 meters high, adjacent to the glacial sediments (the ancient esker stretching from the north to the south almost from Priozersk to Pyatirechye), are recorded along the western shore of Ladoga. They were breached by a water flow in 1818 in the area of the present mouth of the River Burnaya (Gulf of Taipole).

It should be emphasized that the expected overlap of the runoff from Ladoga could be achieved only as a result of time-combined block movements on the Karelian Isthmus caused by the activation of isostatic uplifts of the northern Ladoga area, an increase in moisture content and a change in the flow direction from the Saimaa system. The relative lowering of the southern part of the basin could lead to the breakthrough of water from Ladoga and the formation of the Neva river (or a significant increase in runoff along the channel of the Old Neva, if it existed before these events, that is, there was a bifurcation of the flow from Ladoga).

The River Burnaya was formed as a result of a sudden breakthrough in the waters of the lake Suvanto (Sukhodolskoye) through the man-made channel and its descent to Ladoga only in May 1818. The level of Lake Suvanto dropped by 11 m, and its bottom was exposed on an area of more than 5000 hectares. The protuberance flowing from it to the west in the Vuoksi River was completely dry, in its place a rocky isthmus was formed. It was from this time on Vuoksi flowed back and began to flow into Lake Ladoga, and the numerous lakes of the Karelian Isthmus sharply lowered their level and became shallow. This was due to a 10-11 m drop in level of Lake Suvanto and other local erosion basins in the Vuoksi basin. Significant changes were also caused by a further artificial increase in flow at the site of the river Vuoksa - Lake Suvanto in 1857 and the formation of the Losevskya channel. This event also affected the entire hydrographic network of the Karelian Isthmus and entailed an appropriate restructuring in the structure of its landscapes (Isachenko, 1995, 1998). Numerous lakes of the Karelian Isthmus dramatically reduced their level, became shallower and substantially reduced the size of the water areas as a result of the reduction of local erosion bases in the basin of the Vuoksa River.

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