LAKE GALICH DURING THE LATE VALDAI (WEICHSELIAN) GLACIATION

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Lake Galich is located in the central part of the East European Plain, in the region where glacial relief of the Moscow stage of the Dnieper glaciation is widespread (the Warthe stage of the Saale glaciation). This territory lies outside the area of the Late Valdai (Late Weichselian) glaciation, but its northern part was partly occupied by the large proglacial lakes during the Last Glacial Maximum (LGM) and during the subsequent main stages of this glaciation. After melting of the glacier, these vast lakes did not preserve for long, and as the river valleys incised, most of them were drained. Only the lakes located in more favorable tectonic environment persisted, in particular, those within the wide Yaroslavl' tectonic trough, such as Lake Galich and other largest lakes of this region – Pleshcheyevo, Nero, and Chukhloma (Rumyantsev et al., 2015).

Lake Galich (58° 24' N, 42° 17' E, 101.2 m a.s.l.), the largest natural lake in the region, is located in the northeast of the Kostroma lowland, which is bounded by the Uglich-Danilov Upland from the northwest and by the Galich-Chukhloma Upland from the southeast. The lake is 17 km long and up to 6.4 km wide and stretches from west-south-west to east-north-east. The area of the lake is 71.1 km^2, the average depth is 1.3 m, and the maximum depth is 3.5 m. The lake is weakly flowing, strongly overgrown with macrophytes, and at the present stage hypertrophic. Most part of its bottom is covered with a layer of gyttja of 3-8 m thick (the maximum thickness is about 12 m).

Sedimentation in the Lake Galich occurred continuously since the end of the Middle Pleistocene. Over this time, more than 100 m of lacustrine sediments accumulated with undisturbed bedding of layers. After the retreat of the Moscow ice-sheet, which left moraines and fluvioglacial deposits both in the bottom of the basin and on the surrounding interfluves, the accumulation of clays in Lake Galich has begun (Moscow glacial cover …, 1982). In the Mikulino (Eemian) interglacial they were overlain by lacustrine sediments, which are preserved in the deepest parts of the basin (Evseenkov et al., 1967; Pisareva, 1971). Accumulation of lacustrine sediments continued during the Early and Middle Valdai. Based on the analysis of topographic maps, aerial photographs and geological materials available at that time, D.D. Kvasov (1975) suggested that, at the maximum stage of the last glaciation, when the ice-sheet obstructed the flow of rivers towards the north, a chain of extensive lakes formed along its margin. Lake Galich became part of the proglacial Kostroma Lake, which occupied the Kostroma lowland and connected with the Sukhona Lake in the north and the Rostov Lake in the southwest. It is assumed that the shoreline of this vast lake was at about 145 m above sea level during the LGM, at 130 m a.s.l. in the Vepsian stage of the Last glaciation, and at 120 m a.s.l. in the Luga stage (Kvasov, 1975). Analysis of the maps constructed by D.D. Kvasov (1975, figure 7) shows that during all these stages the basin of the present-day Lake Galich occupied the apex of a deep and narrow ingression bay, in spite of significant changes in the levels.

The most comprehensive data on the landscape and climatic conditions and the nature of sedimentation in the Lake Galich during the last glacial epoch were obtained in 1997-2000 within the framework of the projects of the German Science Foundation FKZ 03F13GUS and the Russian Foundation for Basic Research (project No. 98-05-64534) (Velichko et al., 2001a, 2001b). The coring of the deep borehole Galich-2 was carried out near the eastern coast of the lake. It penetrated the Valdai (Weichselian) deposits to a depth of 69 m. Another borehole (Galich-1) was drilled in the central part of the lake; it penetrated lacustrine mud and gyttja to the depth of 11.9 m below the lake floor. A series of AMS radiocarbon dates obtained by Prof. P.M. Grootes in the Isotope Laboratory of the University of Kiel indicates that the 70m thickness of lake deposits accumulated for more than 50 thousand years (Velichko et al., 2001a, 2001 b), beginning from the Early Valdai (= Marine Isotope Stage 4). Accumulation continued during the Middle Valdai iterstadial (MIS 3), the Late Valdai (MIS 2), and in the Holocene up to app. 5 ka BP (calibrated), when this part of the lake basin became filled in, and peat accumulation started on the lake shores. Calibration of the ^{14}C dates using the IntCal13 and Marine13 calibration curves (Reimer et al., 2013) and the construction of the depth-age model on their basis make it possible to determine the positions of the boundaries of isotope stages in the core and calculate the apparent sedimentation rates of lake sediments.

The granulometric analyses of lake sediments (Velichko et al., 2001a) indicate very stable sedimentation conditions that persisted throughout MIS 3 with a steady trend toward an increase in particle size. In the section from bottom to top, clay, heavy loam and medium loam occur with an average accumulation rate of 1.4 mm per year. At the beginning of the Late Valdai (at the boundary of MIS 3 and 2), the sediment accumulation rate does not change, but the fraction of coarse silt (0.05-0.01 mm – the main component of loess deposits) reaches a maximum content (about 60%) in the granulometric composition. Perhaps this reflects the participation of eolian material in the composition of the lake sediments of this age. Simultaneously, the content of the fine particles (<0.005 mm) is reduced by almost 20%, which can be explained by a decrease in the activity of chemical weathering processes due to a considerable cooling. In the second half of the Late Valdai, after LGM, the mean accumulation rate decreases to 0.8 mm per year, although the particle size of the sediments increases: the medium loam is overlain by a light one, then by a layer of strongly silted mixed-grained sand and again by light loam (Velichko et al., 2001a). Apparently, these changes were associated with a less stable (intermittent) accumulation of sediments in conditions of greater unevenness of rainfall and water flow due to the general aridization of climate. The formation of a sand layer in the deposits of Lake Galich can be presumably compared with the stage of the Younger Dryas at the end of the Last glacial epoch. Sedimentation in the lake sharply accelerated in the Middle Holocene, about 7 ka BP, when in the conditions of significant warming the productivity of the lake increased, and the accumulation of mineral deposits was replaced by the formation of gyttja.

The results of pollen analysis (Velichko et al., 2001a, 2001b) make it possible to reconstruct the changes in vegetation and climate on the territory surrounding the lake during much of the Valdai glacial epoch. During the last interstadial warming of the Middle Valdai (estimated age 32-24 ka BP) the vegetation was of a periglacial forest-steppe type; open forests and woodlands were then formed by spruce, pine and tree birch. In the maximum stage of the Last glaciation (24-17 ka BP) the proportion of woody vegetation, especially of spruce forests, was reduced, primarily due to the arid climate. The periglacial-steppe communities with *Artemisia* prevailed, with limited participation of pine forests. The more intensive sedimentation not only of coarse silt, but also of sandy fractions at this time indicates the development of erosion on the slopes surrounding the lake, poorly protected by disturbed vegetation. This is also indicated by an increase in the proportion of Mesozoic spores, reworked from the terrigenous deposits of the Early Cretaceous and Jurassic age widely spread in the area (Velichko et al., 2001b).

At the beginning of the Lateglacial warming (about 17 ka BP), the role of forest communities with the participation of birch, and later also spruce, increased, while the composition of herbaceous communities remained close to that of the maximum stage of the Last glaciation. In the landscapes around Lake Galich, open forest, shrub, periglacial-steppe, and meadow communities occurred. Spruce played an important role in the forest communities. In the Younger Dryas, the processes of slope erosion sharply intensified and sediment yield from the area surrounding the lake increased, resulting in the accumulation of sandy material in the lake. The Younger Dryas was the last stage when in this region in the conditions of cold, continental, and relatively arid climate, periglacial-steppe vegetation spread.

The results of comprehensive studies of the deposits of Lake Galich, however, do not yet make it possible to unequivocally solve the question of whether Lake Galich was part of the huge Kostroma proglacial lake during the Late Valdai maximum. According to the hypothesis of D.D. Kvasov (1975), during the LGM the water level in the Kostroma lake reached 145 m a.s.l., while the deposits of the same age in Lake Galich, according to our studies, lie at the height about 80 m a.s.l. Consequently, the water depth at the top of the gulf of the Kostroma Lake corresponding to the present Lake Galich basin, at a distance of no more than 15 km from the shore, was to reach 65 m. During the Middle Valdai interstadial, this ice-dammed lake has not yet existed, and the depths in the Lake Galich then probably did not exceed 10 m (similar to the early Holocene conditions). In connection with this, it seems unlikely that such a dramatic change in the depth of the lake did not cause any appreciable changes in the textures of the bottom sediments. However, due to the "marginal" location of the basin of Lake Galich within the Kostroma proglacial basin, the area from which sediments would have been transported into this basin by incoming rivers even at its highest stage would be close to the modern one, since the drainage basins of the main rivers flowing into Lake Galich lie to the east and south of it. The texture of the bottom sediments accumulated during the post-maximum half of the Late Valdai glaciation indicate the development of erosion in the catchment area, and perhaps even some catastrophic washout episodes in the sparse vegetation conditions, but there is no pointers to the existence of a vast and deep (more than 30m) proglacial lake in place of a modern Lake Galich. For a reliable solution to this problem, further research is necessary, in particular, the study and dating of sediments on high terraces presumably of lake origin in the Lake Galich basin.

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LITHOLOGY AND SEDIMENTARY GEOCHEMISTRY OF CORE CO1410 FROM LAKE IMANDRA (KOLA PENINSULA, NW RUSSIA)

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The Late Quaternary climatic and environmental history of the Kola Peninsula, which is one of the key areas for study of glacial-preglacial-postglacial environments in the European Arctic, has been the focus of many palaeoenvironmental studies since the end of 19th century. However, Lake Imandra – the largest lake in the European Arctic – has not yet been properly studied, and even no one long core