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AREA AND VOLUME CHANGES OF THE LAKE ONEGO IN THE LATE GLACIAL TIME

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Formation and development of lakes during and after ice sheets retreating were evident to be one of the crucial factors in shaping the landscape, regional climate changes, making an impact on the global ocean-climate system [Clark et al., 2001]. While development of large proglacial lakes (Agassiz, Baltic Ice Lake and etc.) are well studied, the history of relatively small ice-lakes, especially associated with southeastern and eastern flanks of the Scandinavian Ice Sheet (SIS), as well as their meltwater volumes and drainage routings remain unclear [Larsen et al., 2014].

Lake Onego (61°42´N, 35°25´E) is the second largest lake in Europe with surface area approximately 10 000 km^2. The lake is located in the tectonic depression in suture zone of Fennoscandian Shield and East European Platform. Mainly tectonic forces formed the Onego lake depression; however, Pleistocene Scandinavian glaciations significantly affected its structure. The lake depression was numerously enveloped by the ice streams during glaciations and fresh and sea waters in interglacial periods [Stroeven et al., 2016]. In the Late Weichselian time, the lake depression was covered with the Onego ice stream of the White Sea ice stream complex located in the southeastern part of the SIS. The retreat of the Onego ice stream in the Late Glacial time led to the formation of the proglacial lake and its evolution during and after the ice sheet retreatment.

Several original models of the Onego lake depression deglaciation in the Late Glacial are presented. The models differently assessed sizes of the lake, glacioisostatic uplift of the territory, and location and altitude of drainage thresholds. Demidov's [2006] model was created on the basis of acomprehensive study of ancient costal and forms and bottom sediments, used new and previously obtained data on the geological and geomorphological structure of the lake depression, paleomagnetic and radioisotope dating of sediments. The model aggregated all the available isobase values until that time together with a new paleo dates and presently is the most detailed of them.

The studied area lies in North-West part of Russia between the coordinates 60° N, 30° W and 65° N, 39° W and covers 570 km from North to South and 502 km from West to East. The GIS method by Leverington et al. [2002] was applied to reconstruct such a wide region. The primary source of the modern elevations was the DEM developed by J. Ferranti [2018] with spatial resolution three arc seconds, which was complemented with Onego lake depression and depressions of other 125 lakes, situated within the largest stage of the Onego lake development.

Quantities of sediment deposition and erosion in the lake basin were not accounted during the calculations and interpretation of results, because taking them into account resulted in only 1 % larger lake volume, how it was shown earlier for neighbor locations [Jakobsson et al., 2007]. Geo-referenced calculations and map algebra operations with DEMs were implemented with the ArcGIS 10.2.2 with Spatial Analysis package. The spatial resolution of the combined DEM, involving modern topography and bathymetry, was 90 m.

Ice margins were used only for proglacial stages of the lake development in Late Glacial time (14.5-13.2 Cal. yrs BP). The general ice margins configurations were derived from those of Demidov [2006] with minor modifications. The first two stages of the proglacial lake formation were evolved by Demidov [2006] using Luga (14.5 Cal. yrs BP) and Neva (14.0 Cal. yrs BP) ice margins positions [Saarnisto, Saarinen, 2001]. The next two stages (13.3 and 13.2 Cal. yrs BP) were evolved by Demidov [2006] based on interpretations of moraine and stratigraphic evidence. Ice margins were digitized from the preliminary georeferenced sketches. Later they were adjusted in accordance with glacial and fluvio-glacial landforms locations using topographic maps and geomorphological charts.

Isobase values for Late Pleistocene period were adopted from works of Demidov [2006] involving all previously available isobase data. The tilt of the depression 13.3 Cal. yrs BP was accounted for entire the Late Pleistocene while it was supported with maximum of data points (12) regularly distributed over the studied area. To take into account the lake level change in other stages in the Late Pleistocene the water level was corrected by its difference between 13.3 Cal. yrs BP and the target stage. Glacioisostatic uplift was not accounted for period 14.5 Cal. yrs BP, because only one point of water level was available.

Area and volume calculations were implemented using ArcGis 10.2.2 software with spatial analysis package. The method of GIS reconstruction and uncertainty calculations are described in a detail in [Zobkov et al., 2017]. Palereconstructed maps of different periods in the Late Pleistocene are available online [Subetto et al., 2018]. Volumes, areas, mean and maximum depths for six stages of Lake Onego in the period from 14.5 to 12.3 Cal. yrs BP are given in Table 1.

Table 1

Volumes, areas, mean and maximum depths of the Onego paleolake in different periods. Confidential interval with α=0.05

Period, Cal. yrs BP	Volume, km^3	Area, km^2	Mean depth, m	Max depth, m
14.5	180 ± 5	2710±64	66.5±0.5	114±2
14.0	795.5 ± 72.5	14 790±684	53.5±2.5	168±5
13.3	1639.5±166.5	32 330±1480	50.5±2.5	184±5
13.2	1201±117	24 880±1080	48.5±2.5	174±5
12.4	1080±112	22 590±1170	47.5±2.5	169±5
12.3	967±105	21 480±1150	44.5±2.5	164±5

The results allow us to track back the quantitive changes that took place in the Onego lake basin beginning from the last glaciation. In the Late Pleistocene maximum fluctuations of water volume and area were observed. They were generally resulted from ice sheet melting and opening of new water thresholds during glacier retreatment to the North. Our reconstructions of Late Pleistocene period confirmed the discharges directions and formation of Lake Onego through six main stages proposed by [Demidov, 2006].

Now only the one model of the Onego lake development by Gorlach et al. [2017] with area and volumes estimates is available. The model suggests two stages of Onego proglacial lake development, that were interfere with ours at 14.4 and 13.8 Cal. yrs BP. The first one is proglacial lake formation stage in south part of the lake depression and the second one represents partial depression deglaciation. Taking into account linear trend of area and volume raising in this period it is allowed us to estimate the volume and area at the same periods as Gorlach et al. [2017]. However, data comparison shows high discrepancy in the results: our model suggests that 14.4 Cal. yrs. BP the area and volume of the proglacial lake in average were 5080 km^2 and 304 km^3, while Gorlach et al. [2017] reports 820 km^2 and 21.95 km^3 respectively. At 13.8 Cal. yrs BP ours results shows the area 19 900 km^2 and volume 1030 km^3, while Gorlach et al. [2017] reports 6852 km^2 and 131.91 km^3 only. Despite the numerous simplifications, employed by Gorlach et al. [2017], namely using the robust GTOPO30 DEM data in the studied region and modest glacioisostatic uplift interpolation between 19 and 12 Cal. yrs BP followed by Ågren, Svensson [2007], the observed strong discrepancies seemed only partially linked with them.

The largest discrepancies seemed to be coupled with ice margins positions, as it was shown in [Leverington et al, 2002]. Gorlach et al. [2017], as well as our model, applied end-moraine positions from Saarnisto, Saarinen [2001] and Demidov [2006]. However, over the lake surface ice margins were interpreted differently: for both stages, ice margins by Gorlach et al. [2017] were southward from ones evolved by Demidov [2006]. As a result, relatively small differences in ice margins positions led to manifold variation in area and volume estimations. Taking into account linear trend of area and volume rise in our study it is possible to adjust the time scale in work Gorlach et al. [2017].

In the work Gorlach et al. [2017] 14.4 Cal. yrs BP the initial phase of the first deglaciation stage was reconstructed: that time the ice margin remained southward from the current lake shoreline which coincides with 14.6 Cal. yrs BP of our model. 14.5 Cal. yrs BP we reconstructed the last phase of this stage, then ice margin was northward from the current shoreline, but Svir' outlet was still dammed by the ice. The same is valid for the second stage (13.8 Cal. yrs BP), which initial phase of lake surface deglaciation Gorlach et al. [2017] reconstructed (14.3 Cal. yrs BP in our model), while the last phase (14.0 Cal. yrs BP) was shown on our reconstructions where the ice sheet released most part of the lake surface, but its tongue remained on Zaonesh'skii Peninsula.

It is obvious from the comparison that ice margins positions and time scales discrepancies are the major factors of the area and volume uncertainties, however, in the luck of the information about their variations we were unable to account them statistically.

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PALEOECOLOGICAL EVIDENCES FOR THE LATE PLEISTOCENE LAKE VEGETATION IN THE SOUTH OF THE VALDAI HILLS (BASED ON PLANT MACROFOSSILS DATA)

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The complex study of sections of the Upper Pleistocene lacustrine sediments located in the marginal parts of the last ice sheet provides paleocological records that contribute to an increased understanding of long-term environmental changes during the Late Pleistocene. These investigations contribute also to the reconstruction of the boundaries and dynamics of the Valdai (Weichselian) glaciation. Buried lake-swamp sediments rich in organic matter make it possible to use both paleobotanical and radiometric methods to determine their choronostratigraphic position.

The present paper is focused on paleobotanical, especially paleocarpological, study of the Upper Pleistocene buried lacustrine-palustrine sediments located in the Central Forest State Natural Biosphere Reserve. The study area is situated 360 km west of Moscow (the Tver' region) in the south of the Valdai Hills. The boundary of the Valdai ice cover was situated 15–20 km to the north of the Natural Reserve (Chebotareva, Makarycheva, 1974; Velichko et al., 2004). Geological and geomorphological studies have shown that buried lacustine and palustrine deposits were common in the Natural Reserve. They accumulated in isolated depressions on the moraine of the Moscow stage of the Dnieper glaciation epoch (Puzachenko, Kozlov, 2007).

The most complete Upper Pleistocene section was investigated earlier by N. N. Sokolov. Palynological analysis showed that the section contains Mikulino (Eemian) and Early Valdai (Early Weichselian) deposits (Sokolov, 1948). However, Minaeva et al. (2005) supposed that the buried organogenic sediments of the Natural Reserve are of Middle Valdai age on the basis radiocarbon dating and analysis of macroscopic plant remains from the upper part of the buried peat. Recently, scientists of the Institute of Geography RAS and Severtsov Institute of Ecology and Evolution RAS accomplished an additional complex study of four sections of buried lacustrine and palustrine deposits in the Natural Reserve (Fig. 1).

Section Natural Reserve-1 ("Sokolov borehole") is situated at a steplike part of a slope of a Moscow moraine range in the southern part of the Natural Reserve. Drilling revealed (from bottom to top): carbonate clays with gruss (moraine), fluvioglacial, lacustrine and palustrine deposits about 680 cm thick. They are overlain by loesslike loam, heavy loam and Holocene peat (Fig. 1). Section Natural Reserve-2 resembles section Natural Reserve-1 by it's geomorphological position. It is also situated on a steplike part of a moraine slope. The thickness of buried organogenic deposits (peat and organic-