

Proglacial lakes at the periphery of the southeastern LGM limit: configuration, chronology, degradation

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ABSTRACT. We present the new results concerning the chronology, distribution and dynamic of the proglacial LGM lakes in the valleys of the Severnaya Dvina and its largest tributaries Vaga and Sukhona. Our results refute the hypotheses of the extensive distribution of proglacial lakes and their flow to the south during the LGM. The lakes were local, with an unstable hydrodynamic regime and extended to a distance of 100-170 km from the ice sheet boundary.

Keywords: Southeastern periphery of the last glaciation, ice-dammed lakes, reversal runoff, Severnaya Dvina river basin

1. Introduction

During Late Pleistocene, Scandinavian ice sheet dammed the northward runoff of the rivers in the North and Northeast of the East European Plain, and proglacial lakes formed in the large river valleys. Accordingly, the southeastern lobe of the last Scandinavian ice sheet blocked the Severnaya Dvina River and its large tributaries that could lead to the formation of ice-dammed lakes.

First the idea of ice-dammed lake development in the Severnaya Dvina River valley and its large tributaries during the LGM was proposed by Krasnov (Krasnov, 1948) and then supported by Kvasov who reconstructed the Kotlasskoe proglacial lake in the Severnaya Dvina River valley, the Vaga proglacial lake in the Vaga River valley and the Sukhonskoe proglacial lake in the Sukhona River valley (Kvasov, 1975). The latter had the connection with the Kostromskoe proglacial lake and, consequently, with the system of the Upper Volga proglacial lakes (Kvasov, 1975).

In addition, Sukhona was not an individual river in the Late Pleistocene but consisted of the Eastern and Western Sukhona. Between these rivers, the Main Watershed of the East European Plain passed through the modern mouth of the Uftyuga River (Gosudarstvennaya..., 1989). The Western Sukhona flowed into Sukhonskoe Lake. During the advance of the Late Valdaian ice sheet, the Sukhonskoe Lake level rose to 145 m a.s.l. and had a runoff to the Kostromskoe proglacial lake (Kvasov, 1975). In the Holocene, the lake was drained, its erosion base level was lowered,

that led to the activation of river cutting. As a result, the Western Sukhona was intercepted, and a modern runoff was established (Gosudarstvennaya..., 1989). The modern lake Kubenskoye is a relic of the Sukhonskoe palaeolake (Kvasov, 1975).

At the beginning of the 21st century, a series of reconstructions of the huge damming of the Severnaya Dvina basin rivers was proposed for the last glacial maximum (LGM) with exceeded runoff threshold of 135 m a.s.l. and reverse runoff to the Caspian basin (Lavrov and Potapenko, 2005; Lyså et al., 2014; Larsen et al., 2013). According to these reconstructions, a glacial lobe penetrated far into the Vychegda and Vaga valleys which led to the formation of the proglacial lakes. Based on the DEM (Anisimov et al., 2016) with no geological verification, three proglacial lakes were reconstructed for the Sukhona valley: Verkhne-, Sredne- and Nizhnesukhonskoe. On the other hand, limited distribution of the LGM proglacial lakes was proposed in the very lower reaches of the Vychegda (Sidorchuk et al., 2001) or in the middle reaches of Severnaya Dvina (Zaretskaya et al., 2018; 2020a).

2. Materials and methods

We aimed to determine the time and limits of LGM proglacial lakes in the Severnaya Dvina basin. During fieldwork, we traced the proglacial lake deposits (varved clays) upstream from the LGM limits, performed lithostratigraphic studies of the sedimentary successions, sampling for instrumental dating and other analyses.

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3. Results and discussion

Lake Severodvinskoe. The deposits of this proglacial lake were identified and traced starting from the last ice sheet boundary (proximal facies) and continuing upstream (distal facies); the transition to the LGM alluvium was also traced (Zaretskaya et al., 2020b). Maximum thickness (5 m) was observed near the ice sheet boundary – these are continuous massive varved clays with large ice-wedge casts, underlain by sand. Upstream in the earlier studied Tolokonka section with a total thickness of 25–29 m (Maksimov et al., 2011; Lyså et al., 2014), several packs of varved clays interbedded with sand layers with ripple marks were found. The distal facies were observed 25 km downstream from the Severnaya Dvina and Vychegda confluence (75 km from the LGM ice limit). Dating shows that there were three stages of formation and drainage of the lake between 19 and 16 ka; that means that the Severodvinskoye Lake was a proglacial lake with unstable hydrodynamic regime.

Lake Vazhskoe. We traced the ice-dammed lake deposits in the Vaga valley from the lower reaches of the river where they first appear overlaying the LGM tills, to the place of their maximum development (up to 10 m thick) and then to the Verkhovazhie region (170 km from the LGM boundary) where their thickness decreases, and they eventually disappear (Zaretskaya et al., 2020b).

Despite the similarities of the Severodvinskoe and Vazhskoe proglacial lake deposits (sand interbeds with ripple marks, an increase in thickness close to the ice sheet boundary), there are also significant differences. First, in the upper part of varved clays there are organogenic layers, including plant detritus and even autochthonous peat with well-preserved plant remains. Second, we saw no ice-wedge casts in the varved clays, but it was found that they occur in the overlying alluvial sand. Third, the maximum thickness of clays in the Vaga sections is at least twice larger than in the Severnaya Dvina sections. And, fourth, in the Vaga valley, in the lower reaches of the river, there are “paired” packs of deposits of the glacial paragenetic series: the LGM till is continuously covered by the proglacial lake deposits. The organic-bearing varved clays were radiocarbon dated to 14.8–13.5 cal. ka BP, which means that the Vazhskoe Lake was drained no later than 14.8 ka BP. Apparently, the Vazhskoye and Severodvinskoye lakes existed synchronously, but the hydrodynamic regime in the Vazhskoye Lake was stable, the lake itself was larger and deeper and drained only once after the glacier retreat.

Lake Sukhonskoe. We studied the outcrops including the Sukhonskoe Lake deposits at the mouths of Tolshma, Tsareva, Staraya Totma and Gorodishna rivers (the Sukhona River tributaries). Glaciolacustrine sediments (varved-like clays less than 1 m thick) were found at altitudes of 110–118 m a.s.l., and the absolute height of their top limit decreases downstream of the modern Sukhona (Zaretskaya et al., 2021). The clays contain interbeds of sand with ripple marks, indicating the unstable hydrodynamic regime of the basin, as well

as numerous fragments of plant remains. Apparently, the Sukhonskoe Lake itself was formed in a periglacial depression. The “reverse” decrease of the glaciolacustrine deposits’ top limit probably indicates the existence of a glacial forebulge. The Main Watershed of the Russian Plain continued along it, crossing the Sukhona River near the mouth of the Uftyuga River. After the ice sheet degradation and the forebulge relaxation, the slope of the Western Sukhona was “skewed” and joined with the Eastern Sukhona, and the varved clays also received a “reverse” slope. Below the confluence of the Staraya Totma River, no LGM glaciolacustrine sediments were observed (Zaretskaya et al., 2021). The structure the Uftyuga River valley allows us to conclude that during the LGM there was no connection of the Sukhonskoe and Vazhskoe proglacial basins. Drilling in the zone of the proposed connection between the Kostromskoe and Sukhonskoe lakes disaffirmed the existence of a crossflow between them.

4. Conclusions

Our results refute the hypotheses of the extensive distribution of proglacial lakes and their flow to the south during the LGM. The lakes were local, with an unstable hydrodynamic regime and extended to a distance of 100–170 km from the ice sheet boundary.

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Conflict of interest

The authors declare no conflict of interest.

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