





The Reconstruction of the Formation of Lakes and Wetlands and the Related Sedimentation Processes in the Russian Segment of the Vištytis Upland

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Abstract

The Vištytis Upland is a terminal moraine ridge featuring kame hills. There are numerous lakes and wetlands in its depressions. We collected the samples of bottom sediments from a number of lakes and wetlands located at different altitudes. Using the results of the lithological analysis and radiocarbon dating of the lakes' bottom sediments and those of a loss-on-ignition test, we identified the main stages of sedimentation. We reconstructed the formation and development of the lakes of the Vištytis Upland from the moment of deglaciation to the present. Two groups of lakes were distinguished by genesis: (a) the lakes formed in the inter-moraine or inter-kame depressions flooded by melt water; (b) the lakes formed in the thermokarst processes. The lakes of the first type are located at altitudes over 170 m and date back to the Younger Dryas, whereas the lakes of the second type are located below 170 m and their formation occurred in the Younger Dryas—the Preboreal. We conclude that the wetlands located west of Lake Vistytis were the bays of the lake in the Late Pleistocene.

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Keywords

Bottom sediments of lakes · Glacial lakes · Lake formation · Vištytis Upland · Kaliningrad region · Sedimentation · Late glacial · Holocene

Introduction

Studying the environmental transformations of the past is highly relevant, since only our knowledge of the past changes can shed light on how geosystems will be transformed in the future. Lakes are unique natural objects, the bottom sediments of which keep records of the past natural and climatic conditions, ranging from local to global in terms of space and from annual to centennial and to millennial in terms of time. The data on the lithologic structure of lakes' bottom sediments makes it possible to perform palaeogeographic reconstructions and to study the sediment formation and the changes in the hydrological regimes that water bodies went through in the past (Subetto 2009). A poorly explored area, the Vištytis hilly-moraine ridge occupies a special place in regional palaeogeographic studies. For the reconstruction of the sedimentation processes, we chose several lakes and a bog located at different altitudes. In this article, we present a lithological description of Lake Chistoe and the peat-bog of Shombrukh, a digital geological model of the Vištytis Upland, and a reconstruction of the palaeobasins formation.

The Study Area

The studied lakes and bog are located the Vištytis Upland (Fig. 1), which formed during the Baltija (Pomeranian) stage of the Last (Weichselian) Glaciation (Guobyte and Satkunas 2011; Raukas et al. 2010). The Vištytis Upland was one of the first areas of today's Kaliningrad region to be freed from the glacier (Kublitskii 2016). Thus, it contains traces of the oldest lake sediments. Although the topography of the Vištytis Upland is mostly of an inherited nature, there are some inversions. The altitudes are about 50 m in the northwest and 200–300 m in the southeast (Orlenok et al. 2001). In terms of geomorphology, the territory is characterised by facies of push—and thrust-block-types with the prevalence of water-glacial forms, such as moraines, kames, eskers, sandurs, and lacustrine-glacial plains. There is a palustrine wetland comprised by flat and slightly arching upland palustrine plains. With their feet coalescing, the hills form ridges divided by depressions. These depressions are mostly swamped and, in some, lakes are formed.

The climate of the Vištytis Upland is more continental than in the rest of the Kaliningrad Region. The average annual quantity of precipitations is 700 mm, the average annual temperature is +6.5 °C, the average January temperature is −4.5 °C, and the average July temperature is +17.5 °C (Litvin 1999). The predominant soil

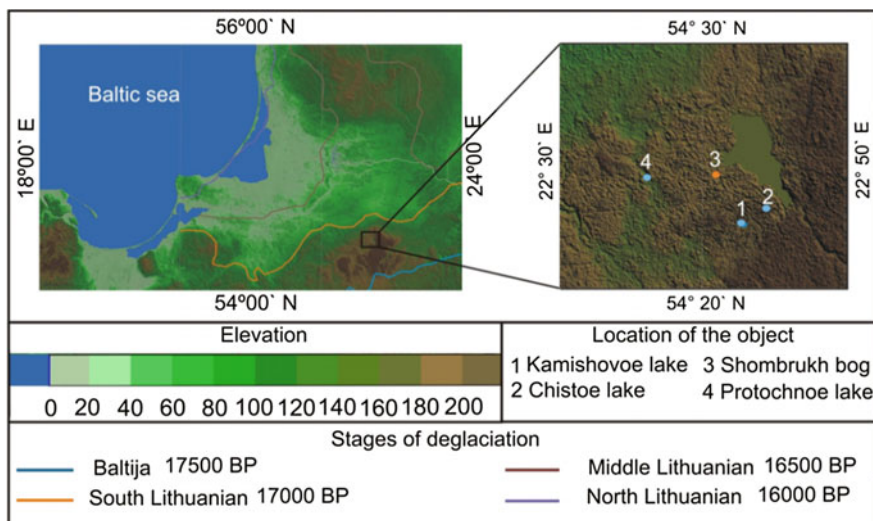


Fig. 1 The location of the study areas, and the stages of the last glaciation

types are brown and cryptopodzolic. Besides, in the depressions, there is marsh soil formed by excessive precipitations. The vegetation cover is diverse: pines and spruces comprise over half of the forest, whereas a slightly smaller area is occupied by small-leaved trees. Broad-leaved forests account for about 10% of the territory (Orlenok et al. 2001).

Methods

Field research was conducted from 2011 to 2015. The bottom sediment cores were sampled by peat corer (the sampler diameter was 7.5 cm for the upper horizons and 5 cm for the denser lower horizons and bogs). A primary visual lithological stratigraphic description was prepared on site, after which each meter column of sediments was placed in plastic containers for transportation. A detailed description, sampling, radiocarbon dating, and a loss-on-ignition (LOI) test were carried out in the laboratory, employing standard techniques (Santisteban et al. 2004). The collected samples were analysed using the conventional advanced radiocarbon method at the Laboratory of Palaeography and Geochronology of the Quaternary period (Saint-Petersburg State University, Russia), at the A. E. Fersman Laboratory of Environmental Geochemistry (The Herzen State Pedagogical University of Russia), and at a laboratory in Poznan (Poland). To determine the type of the bottom sediments, a soil organic matter classification was used: a LOI value of below 2% is

characteristic of clay, 2–6% of gyttja clay, 6–20% of clayish gyttja, and 20% of gyttja proper (Miettinen et al. 2007). A digital terrain model was created using the Global Mapper 16 and the Golden Software Surfer 13 applications.

Results

Lithological stratigraphy A visual lithological description and the chronology of the bottom sediments of Lakes Kamyshovoe, Protochnoe, Chistoe, and the peat-bog of Shombrukh were published earlier (Kublitskii et al. 2014a, b, 2016).

Geochronology A detailed chronological dating was carried out only for Lake Kamyshovoe (Kublitskii et al. 2014a). For Lake Protochnoe, there is one radio-carbon date from the lower horizon that makes it possible to pinpoint the beginning of the lake sediment formation. Using the dating results, the average rates of sedimentation were calculated (Table 1).

Discussion

These water bodies are located at different altitudes in close proximity to each other. The greatest distance between the objects (Lake Protochnoe and Lake Chistoe) does not exceed 8 km. Nevertheless, the lower parts of the bottom sediments sections differ, which indicates that they were not formed under similar conditions (Fig. 2).

Lakes Kamyshovoe and Chistoe, which are located the altitudes of 192 and 207 m respectively, have a similar structure. The lower part of the bottom sediments cores is grey gyttja clay, with a dark-brown gyttja interbed at depths of 1060–1064 cm (Lake Kamyshovoe) and 689–704 cm (Lake Chistoe). This gyttja interbed dates to 13,714 cal. years BP and its formation is associated with the Allerød oscillation (Druzhinina et al. 2015; Kublitskii 2016). A similar horizon was found in the bottom sediments of the lakes in Poland, Lithuania and Belarus (Wachnik 2009; Kabailienė 2006; Novik 2010). The territory under study was effectively ice-free around 16.5–17 cal. k year BP (Hughes et al. 2016), which suggests that sedimentation began in the same period. Therefore, Lakes Kamyshovoe and Chistoe were formed in the depressions of the moraine ridges after the glacier had retreated. From the time of their formation and until the onset of the Allerød, the allochthonous sedimentation type prevailed in the lakes. This sedimentation type was characterised by the predominance of minerogenic sediments over organogenic in the conditions of a cold climate and periglacial vegetation. In the Allerød the bottom sediments structure was transformed—the gyttja clay turned into gyttja, due to the increased role of organic matter in the formation of bottom sediments. The formation of sediments with a high organic content is associated with the improvements in the climatic conditions in the catchment area of the lake.

Table 1 Summary data on the water bodies

The water body and sampling site coordinates	Altitude (m)	The thickness of sediments (cm)	Horizon dated (cm)	Lab. No.	¹⁴ C dating BP	Cal. age BP	The average sedimentation rate, mm/year
Lake Protochnoe 52°24.122' N 22°36.458' E	153	864	831–841	SPb_1223	10,300 ± 100	12,101	0.71
Lake Kamyshovoe 54°22.605' N 22°42.790' E	192	975	838–839	POZ-60,940	11,600 ± 60	13,417	0.62
Lake Chistoe 54°23.302' N 22°43.706' E	207	372	340–344	SPb_1797	10,450 ± 80	12,350	0.3
Shombrukch bog 54°24.207' N 22°40.622' E	187	740	720–730	LU-7260	8620 ± 210	9774	0.71

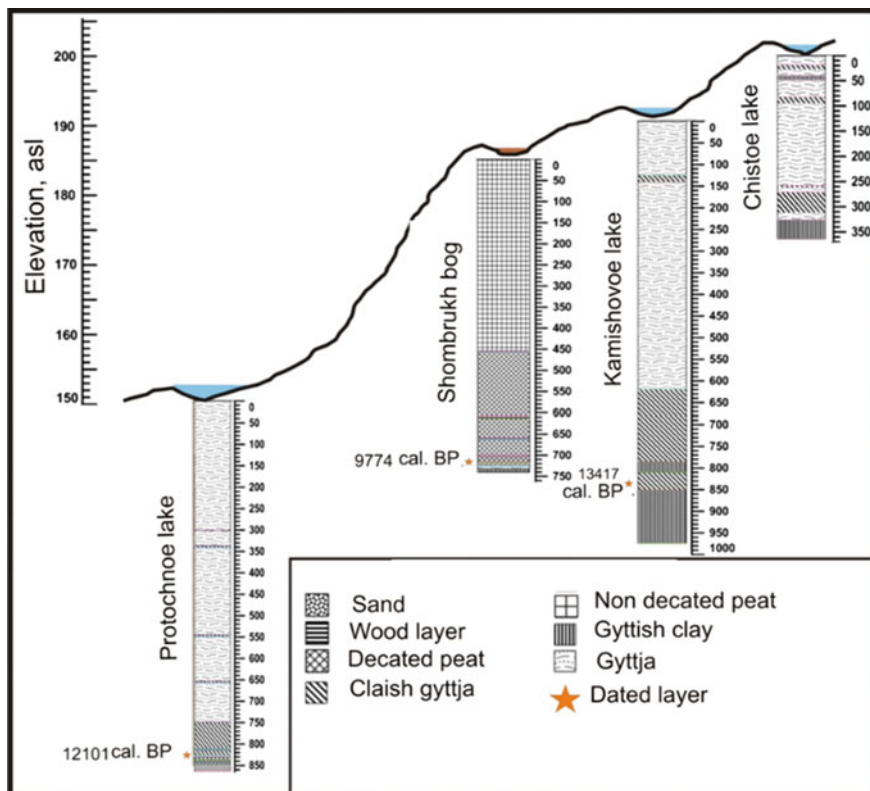


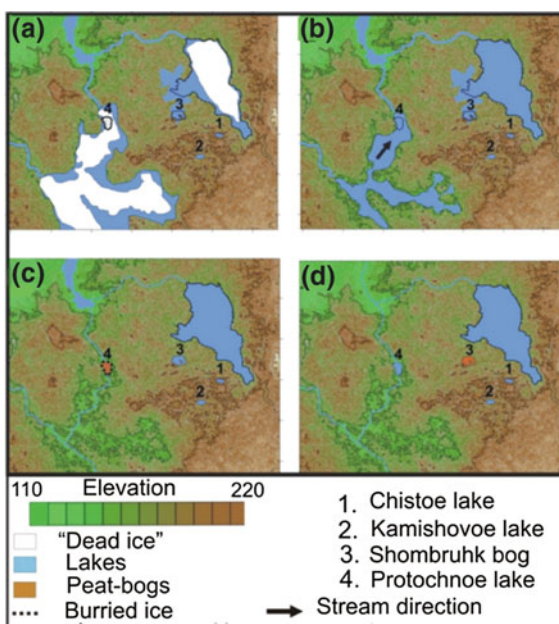
Fig. 2 Lithology, chronology and sedimentation rates of the bottom sediments of the lakes in the Vištytis Upland

Around 12,700 cal. years BP (Druzhinina et al. 2015), the predominantly organogenic gytija was replaced by predominantly mineral gytija. This testifies to the growing role of the allochthonous substances in the sedimentation process that is associated with the declining temperatures of the Younger Dryas. At the beginning of the Holocene (11,700–11,000 cal. years BP), the proportion of organic matter in the bottom sediments started to increase. From the Boreal, the lithology of the sediments was represented predominantly by gytija.

The rates of sedimentation in Lake Kamyshovoe are 2.5–3 times higher those in Lake Chistoe. This is explained by as follows: (1) the samples were taken near the shore, whereas sediments are usually the thickest at maximum depths, where we could not perform sampling for technical reasons; (2) the catchment area of a water reservoir is smaller at greater altitudes, which leads to the reduction in the deposits brought into the basin.

The peat-bog of Schombrukh is located 2 km west of Lake Vistyitis, at an altitude of 180 m. The lowermost part of the bottom sediment section from the bog is clay, which indicates that this basin was a part of a glaciolacustrine basin in the

Fig. 3 A reconstruction of the formation of the selected lakes in the Vištytis Upland. **a** 14000–16,000 cal. years BP; **b** 12,700–14,000 cal. years BP; **c** 11,700–12,200; **d** 9774 cal. years BP—present time



Late Glacial. During the formation of clays, the bog was 7–8 m below the present level (if the thickness of the Holocene peat is subtracted), thus, the bog basin could be flooded with the waters from palaeo-Lake Vistytis. Today, the altitude of the lake is 172 m (Orlenok et al. 2001) but, in the Late Glacial period, it could be 180 m (Fig. 3b). The water level of Lake Vistytis could go down during the drainage of the Baltic Ice Lake, 11,690 cal. years BP (Jakobsson et al. 2007; Björck 1995). Later, in an already isolated small lake, the gyttja and peat started to form (Fig. 3c). The sand layers occurring in the gyttja and even in the lower peat horizons are associated with the drainage and isolation of the bog basin from Lake Vistytis. Above the sand interbed lies a 7-m peat stratum, which reaches the day surface. The stratum formed after 9500 cal. years BP.

Lake Protochnoe is located at an altitude of 153 m. The sediments of the lower part of the section are peat overlain by sand and gravel, the dimensions of which increase with depth (Kublitskii et al. 2014b). This stratigraphy suggests two scenarios of the lake formation. Firstly, the reservoir might have formed by the melting of dead ice blocks. This type of lake genesis is typical for the region under study (Nalepka and Jurochnik 2013). The second scenario is associated with the melting of the buried “dead ice” blocks during deglaciation. To test the second scenario, we created a digital relief model, the analysis of which suggests that the depression located south of the lake could indeed have been covered by dead ice (Fig. 3a). The meltwater streams flowed northward through the lake basin (Fig. 3b). Lake Protochnoe was formed within the area of dead ice melting in the valley of the palaeo-water discharge. The sand and gravel, which were uncovered below the

peat, are alluvial sediments. After the dead ice had melted, the swamping of the lake basin began (Fig. 3c). This happened 12,100 cal. years BP, i.e. at the end of the Younger Dryas. The insufficient number of dates precluded an estimate of the precise age of the wetland ecosystem. Since we know that the thickness of the peat is 15 cm, it is possible to estimate the time of the formation of the bog, which is about 50–100 years. As the buried ice melted, the bottom of the basin subsided. As a result, the wetland ecosystem transformed into a lake ecosystem and the process of accumulation of peat was replaced by the that of silt.

Conclusion

All studied lakes and wetlands of the Vištytis Upland formed during the Late Glacial period. By their genesis, they can be divided into two types: (1) the glacial lakes (formed in the inter-moraine or inter-kame depressions by meltwater flooding); (2) the thermokarst lakes. The lakes of the first type are located at higher altitudes. In the lakes of this type, the process of sediment formation began as the glacier started to retreat. In the sediments of the Younger Dryas, the mineral fraction (clay and gyttja clay) predominates. A distinctive feature of the most ancient lakes is that the clay layer contains a gyttja interbed, which is dated to the Allerød interstadial. The reservoirs of the second type are at altitudes below 170 m. The onset of lake sediment formations is associated with the Pleistocene/Holocene transition. The sediments of a part of the uncovered column are peat overlying sand. The area of the peat-bog of Schombrukh might have been flooded by palaeo-Lake Vistytis. Today, the palaeolake is located at an altitude of 172 m. During the Late Glacial, it could have been at 180 m.

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