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The relative sea level changes and aeolianprocesses on the Eastern coast of the White Sea (Gorlo Strait) during the Late Glacial and Holocene (based on studies of Lake SrednyayaTret')

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ABSTRACT. Geomorphological, ground penetration radar profiling and paleolimnological investigations were carried out in the Lake SrednyayaTret' (66.014009°N, 41.086294°E; 7.3 m ASL). Bottom sediments from the three boreholes were studied. Lithologostratigraphic description, grain-size and diatom analyses were carried out, loss on ignition, C_{org}/N_{ogr} was determined. Radiocarbon ages were obtained from the lower horizons of post-glacial sediments. Signs of Late Glacial transgression (earlier ~12.1 kyr. cal. BP) and Early Holocene regression (started between ~12.1 and ~10.3 kyr. cal. BP) were determined. The next filling of the lake basin can be compared with the Middle Holocene transgression. At the same time sea waters did not penetrate into the lake basin. The beginning of this stage was apparently accompanied by intensification of coastal aeolian processes.

Keywords: RSL, aeolian processes, palaeolimnology, grain-size analysis, diatom analysis, loss on ignition, C_{org}/N_{org}, Late Glacial, Holocene, White Sea, Gorlo Strait

1. Introduction

Gorlo Strait is a key area for understanding the White Sea level dynamics after glaciation degradation. It is also an area with strong winds and active coastal aeolian processes (Repkina et al., 2019). In recent years, the age of ancient coastal lines on the southeastern coast of the Strait has been established and the main features of relative sea level (RSL) during the Holocene have been determined. The RSL stabilization (~7.3 - ~3.1 kyr. cal. BP) at levels above modern was determined (Repkina et al., 2019; Shilova et al., 2019; Zaretskaya et al., 2020). The distribution of Holocene marine sediments has been traced by diatom analysis up to 4 m a.s.l. (Shilova et al., 2019). The coastal landforms (beach rides and spits) traced up to 5-7 m a.s.l. (Repkina et al., 2019). Differences in the height of RSL indicators require explanation. The timing and level of Late Glacial transgression and the relationship between RSL changes and rhythms of Aeolian processes also remain under discussion. The first results from the study of Lake SrednyayaTret' add to the evidence to solve these issues.

2. Materials and methods

Lake SrednyayaTret' (7 m a.s.l., 66.014009°N, 41.086294°E) is located on the eastern coast of the White Sea (Gorlo Strait) between the Intsy cap and the month of the Ruch'i river. A diameter of lake about ~1 km and depth about ~1.9 m. The lake basin is bounded by smooth moraine ridges and sandy eskers (10-32 m). The lake basing is drained by a channel which inflow into the estuary of the Ruch'i River in 10 km upstream of its mouth. According to the relief of the basin, if the RSL rose above the lake's threshold, it became part of the estuary. The salinity of the water must have been less than in the open sea. And if the RSL did not reach the lake's threshold, transgressions could only affect

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the lake by changing the hydrogeological situation. These events could be recorded by geochemical and micropaleontological indicators. Therefore, the Lake SrednyayaTret' is an ideal site for RSL studies.

Field investigations included DGPS and surveys, geomorphological and ground penetration radar profiling (GPR) and coring of the lake sediments.

Coring was carried out from the ice using a Russian peat corer at 4 points (ST1-ST4). It was accompanied by lithological and stratigraphic description according to the methodology (Subetto, 2009) and core sampling for analytical studies and radiocarbon dating. GPR studies were carried out using Zond-12e ground penetrating radar and 300 MHz antenna (average depth - up to 10 m, resolution - first tens of centimeters). The first results of core analyses were obtained. For samples from lower horizons of cores from core sections ST2, ST3 and ST4, grain-size, loss on ignition, Corg/Norg were determined. The sediment dating core was done in the Laboratory of Radiocarbon Dating and Electron Microscopy of the Institute of Geography, RAS, and the Center for Applied Isotope Studies, University of Georgia, USA, according to the procedures adopted in these laboratories.

3. Results

Radarograms show the surface of the lake bottom, uneven basin and layered sediments between them. On the sides of the basin and above the glacial ridges, the thickness of layered sediments does not exceed 0.5 m; in depressions between the ridges, it increases up to 4 m.

The lake sediment sequence is fully penetrated by ST2 core section (water depth 183 cm, sediment thickness 457 cm), which is located in the center of the basin. Core sections ST1 (water depth 145 cm; sediment thickness 19 cm) and ST3 (water depth 152 cm; sediment thickness 200 cm) were cored on the sides of the basin. Core section ST4 (water depth 120 cm; sediment thickness 35 cm) was cored on the moraine ridge.

Four lithostratigraphical sequences (units) in the lake sediments have been identified. These units have a slight difference in lithology and sediments thickness in core sections:

Unit 1. The bottom sediments are silty-clay or silty-sand (2-30 cm) with LOI less than 5% and a Corg/Norg ratio of <10 to 10.3. According to (Lamb et al., 2006), Corg/Norg values <10 are typical for marine sedimentation conditions. No diatoms were found. According to radiocarbon age from the core ST2, the sediments were formed earlier than ~12.1-12 kyr. cal. BP.

Unit 2. In the most complete sections (ST2 and ST3), the Unit 1 sediments recovered by peaty gyttja layer (36-51 cm). The age of the basing layer (core ST2) is ~10.3 kyr. cal. BP. The mineral part of this unit is represented by silt and clay. LOI content varies from 40 to 95% and Corg/Norg values from 11 to 37. Diatoms are represented by lake-swamp species in the lower part of the core ST2 and it is replaced by lacustrine species in the upper part.

Unit 3. On the western side of the lake basin closer to the seashore (borehole ST3), interbedded dense sandy silts and silts with plant remains (48 cm) lie on the peaty gyttja. In the centre of the lake (borehole ST2), the horizon is represented by sandy gyttja with plant remains and thin interlayers of sand (46 cm). The sand grains are poorly rounded and unrolled. In the core from the core ST3, the LOI ranges from ~2 to 24% and the Corg/Norg value varies from 52.9 to 19.2. At the base of the layer (contact with the peaty gyttja) Corg/Norg drops sharply to 5, which is typical for marine sediments (Lamb et al., 2006). Diatom content is uneven. Lacustrine and swamp diatom species are present in layers of sand enriched with fine organic material. In the sand and coarse detritus diatoms are absent.

Unit 4 and Unit 5 are represented by typical lake sediments - dark brown to olive gyttja (up to 238 cm), and silt (up to 49 cm). The sediments contain sands, silt and reare plant remains.

Unit 6. At the depth of about 1 m and up to 2 m from the open sea shore, the modern lake sediments are represented by fine-grained sands. They are uncovered by core ST1. The sands enter inside the lake due to erosion of its shores and with aeolian flows. The sources of aeolian sands are beaches of the open sea shore and glacial deposits.

4. Duscussion

Unit 1 can be compared to post-glacial transgression. Extremely organic-poor sediments accumulated up to ~12.1-12 kyr. cal. BP. Probably, in the conditions of an isolated bay of the Ruch'i River estuary. Probably, there was a glacier margin. The data obtained correspond to the transgression dates (~13-11.5 kyr. cal. BP) established for the White Sea (Kolka and Korsakova, 2017).

Unit 2. The beginning of the formation of peat deposits (between ~12.1-12 and ~10.3 kyr. cal. BP) is probably associated with bog development in the previously dried basin. The atering of the basin gradually increased, and a stable freshwater reservoir was formed. At the end of the stage, the lake level seems to have been lowered. In the center of the basin (core ST2) diatom associations correspond to lacustrine conditions and at its periphery (core ST3) was overgrown shallow area. Unit can be compared with a late-glacial regression.It is dated in the western part of the White Sea by the interval ~11.5-9.8 kyr. cal. BP (Kolka and Korsakova, 2017). On the eastern coast of the sea, peat with an age of ~10.6-8.5 kyr. cal. BP is correlated with the regression (Repkina et al., 2019; Shilova et al., 2019; Zaretskaya et al., 2020).

Unit 3. The formation of the interval can be associated with the end of the Early Holocene regression and the beginning of the Middle Holocene transgression. The sharp decrease in the Corg/Norg values at the base of the horizon (core ST2) may be a sign of short-term intrusion of sea waters into the lake basin. However, diatom associations do not confirm it. The filling of the lake basin continued, possibly due to hydrological situationcaused by an increase in RSL. On the margin of the basin, close to the open sea, the interstratification of sandy and peaty sediments indicates, possibly, a periodic activation of aeolian transport from the beaches.

Unit 4 and Unit 5 were formed in lacustrine conditions, probably during the mid-late Holocene.

5. Conclusions

The bottom sediment section of Lake SrednyayaTret' reveals traces of Late Glacial transgression that ended later than ~12.1 kyr. cal. BP and regression of the Early Holocene (started between ~12.1 and ~10.3 kyr. cal. BP). The next filling of the lake basin can be compared with the Middle Holocene transgression. However, the assumed by morphological data increase of the RSL to 6-7 m is not confirmed by the results of analytical studies of the lake bottom sediments. Due to the increase in RSL, the shoreline of the sea approached the lake basin. In the bottom sediments this is recorded by interlayers of sand, which, as at present, is brought by wind from sandy beaches.

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Conflict of interest

The authors declare no conflict of interest.

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