GLOFCA PROJECT
«Reducing vulnerabilities of populations in the Central Asia region from glacier lake outburst floods in a changing climate»

Report on task 9A part 2: study of the peculiarities of the development of outburst-prone lakes on moraine-glacial complexes of the Ala-Archa River valley (research is conducted on the basis of the high-mountain glaciological station Adygene)

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Ground survey of the moraine-lake glacial complex in the Adygene River basin in 2023.

Introduction.

Within the framework of the GLOFCA project, field work was carried out to study glacial lakes in the Adygene River basin from August 19 to August 29, 2023. The research was carried out by Satarov S., Junior Researcher of the 2nd Department, and Musaev T., Junior Researcher of the same Department, together with the staff of the 1st Department of CAIAG.

The studies were carried out on the glacial moraine-lake complex Adygene, which is located in the basin of the left tributary of the same name of the Ala-Archa River, located on the northern macro-slope of the Kyrgyz Ala-Too Range (Northern Tien Shan), in its central part. The Adygene River basin has an area of 39.6 km^2 [2], and the area of glaciers is 11.1% (4.4 km^2) of the area of the Ala-Archa River basin [5]. The absolute altitude of the Adygene River basin varies from 2370 to 4200 m, and the average slope of the valley is 11^0. The moraine-lake complex (42^0 30′ 10″ N and 74^0 26′ 20″ E) closes the 8-kilometer-long Adygene River valley from the south. The Adygene moraine-lake complex is located mainly in the zone of continuous permafrost. It is known that at similar altitudes in the Northern Tien Shan [2, 3], permafrost reaches a depth of up to 100 m, and the active layer can be up to 4 m thick.

The following types of fieldwork were conducted within the moraine-lake complex area: bathymetric survey of lakes, observations of the lithological composition of moraine deposits, including on glaciers, characterization of the relief of lake basins, and measurement of the temperature of lake water and air.

Location and characteristics of lakes.

Figure 1 shows a schematic map of the surveyed lakes' locations, while Table 1 presents a list of lakes, their numbers, and main characteristics, including those obtained mainly for relatively large lakes, as a result of bathymetric measurements. During the reporting period, some lakes remained unexamined due to their relative remoteness and inaccessibility.

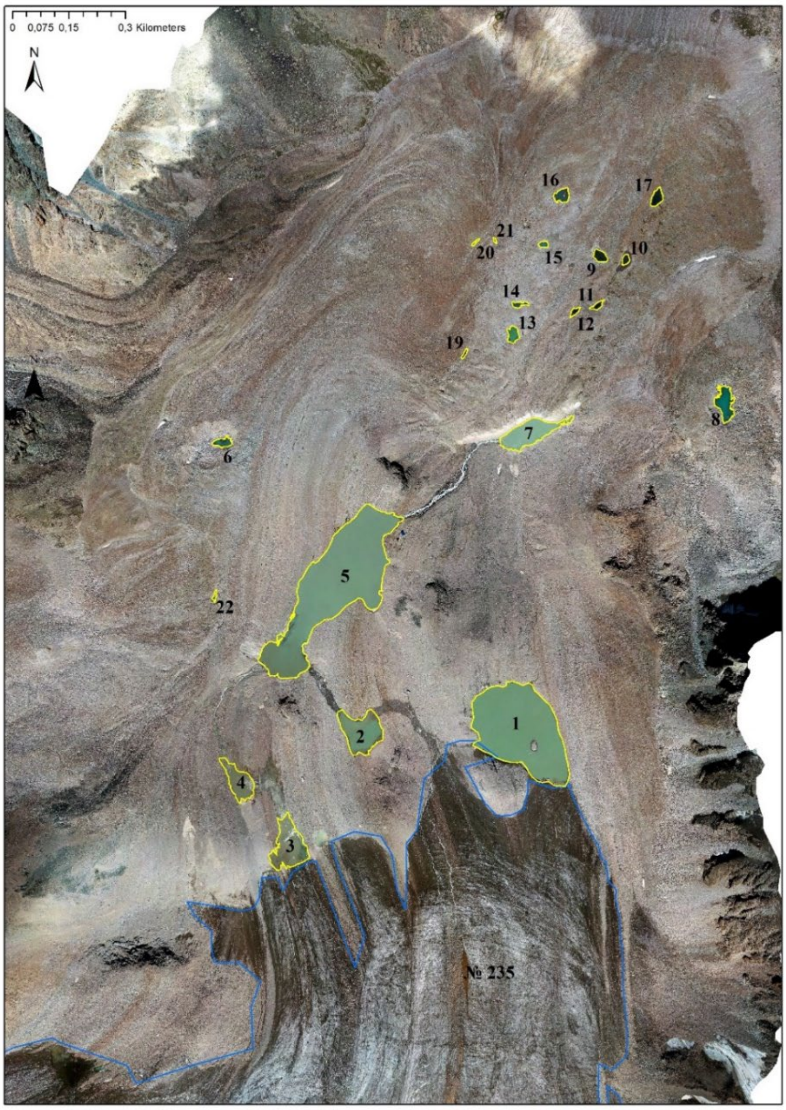


Fig. 1. Location of lakes on the moraine-lake glacial complex in the Adygene River basin.

Table 1

Characteristics of the lakes of the moraine-lake complex Adygene

№ of a lake, name	Area km^2, (m^2)	Absolute water level (m)	Average lake depth (m)	Maximum lake depth (m)	Water volume (thousand m^3)	Area measurement time, day/month/year	Lake volume measurement time/year
1	0,02568 (25568)	3628	4,9	14.3	145,8	21/08/2023	20/08/2023
2	0,005 (5030)	3616	0,8	2,5	4.9	21/08/2023	20/08/2023
3	0,0048 (4800)	3636				-..-	
4	0,0028 (2770)	3620				-..-	
5, Adygene	0,034 (34470)	3585	6,5	22	213	-..-	20/08/2023
6	0,0005	3630				-..-	

	(500)						
7	0,004 (4210)	3499		4.8	14.5	-..-	19/08/2023
8	0,0017 (1700)	3534				-..-	
9	0,0005 (421)	3531				-..-	
10	0,0002 (230)	3530				-..-	
11	0,00022 (220)	3532				-..-	
12	0,00018 (180)	3531				-..-	
13	0,00055 (550)	3528	1.3	4.04	1.3	-..-	
14	0,00025 (250)	3530	0.8	2.2	0.4	-..-	
15	0,0002 (200)	3535				-..-	
16	0,0006 (640)	3535				-..-	
17	0.0006 (570)	3531				-..-	
18, Tez-Tor 1*	0.003 (3000)	3600				-..-	
19	0.0001 (100)	3531	0,5	1,6	0,06		
20	0,00006	3545					
21	0,00004	3541					
22	0,0001 (100)	3612					

(*)– the lake is not included in the diagram (Fig. 1) and was not surveyed in 2023.

Measurements of absolute lake surface elevation in the field using GPS Garmin etrex 20, with an accuracy of ±10-20m, given in Table 1 and used in Figure 2, show that the studied lakes are located in the zone of continuous permafrost.

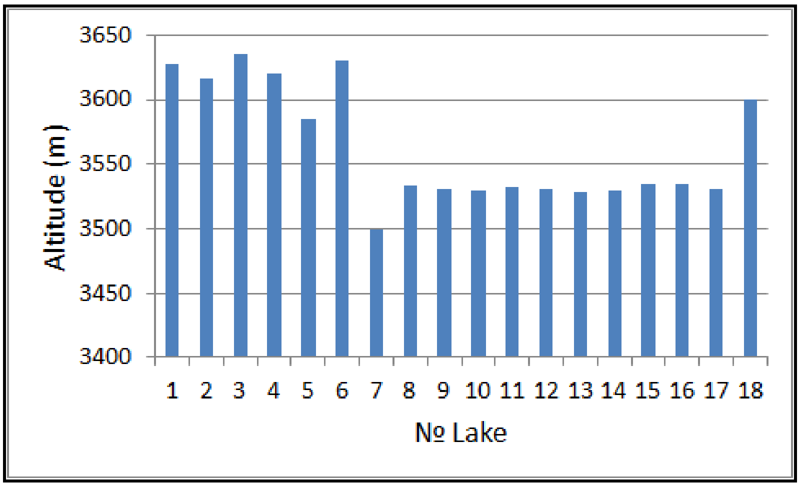


Fig. 2. Absolute heights of lake water levels

Engineering and geological characteristics of lake basins.

The dams and banks of the basins of the studied lakes are formed on a moraine complex consisting of coarse clastic material of various sizes, ranging from boulders of approximately 1 meter in size to gravel with sandy and dusty-sandy aggregate. The characteristic size and texture of moraine deposits in lake areas are shown in Figures 3, 4, 5, and 6. The overall texture of coarse clastic moraine deposits is homogeneous, with a predominance of fragments of similar sizes. For lakes No. 1 and 5, the formation of dams is due to protrusions of the rocky basin foundation covered with variable thicknesses of clastic moraine deposits, some of which emerge above the surface (see Figure 3).

In some cases, as for Lake No. 13, local relatively massive, about 0.4 m thick, deposits of fine-grained sandy-dusty material on the banks of the lake basin are observed, as can be seen in Figures 7,8. The formation of these deposits is likely associated with the action of seasonal surface runoff, transporting fine-grained material across the surface of the moraine complex. This fine-grained material forms both on the surface of glaciers and directly within the moraine deposits, accumulating in separate lake basins. In these fine-grained deposits, along with dusty material of glacial genesis (glacial flour), clayey material of aeolian genesis coming from the glacier surface, where it is constantly accumulated, may also be present. The presence of fine-grained deposits in the moraine complex may contribute to the impermeability of coarse clastic moraine deposits on the bottom and banks of lake basins and promote the long-term existence of lakes with a stable hydrological regime.

Fig. 3 Characteristic size of fragments of loose clastic rocks of moraine deposits forming the dam and banks of the basin of Lake No. 5 Adygene

Fig. 4 Basin of lake No. 10, view from north to south. The banks are composed of clay-rubble moraine sediments with sandy-dusty aggregate

Fig.5 Lake basin No.11, view from east to west. Fragmentary water-filled lake basin formed on coarse clastic moraine deposits.

Fig. 6 Lake Basin No. 13, view from west to east.

Fig.7 Fine-grained sandy-dusty sediments on the western shore of Lake 13.

. Fig. 8 Sandy-dusty sediments on the western shore of Lake 13.

Methodology for lake studies

During the lake study, the coordinates of each lake were determined using a GPS GARMIN etrex 20 with an accuracy of ±5 meters (Figure 9). To determine the water volume, depths of the lakes were measured using a Fish Deeper chirp+ echo sounder with a resolution of 0.15 meters and built-in GPS (Figures 10, 11). In addition, observations of the water and atmospheric air temperature were recorded along with the time of measurements, and the degree of water turbidity in the lakes was visually assessed. Water and air temperatures were measured using an alcohol thermometer with a resolution of 0.1°C (Figure 11), at a depth of 0.1-0.15 meters for water and at a height of 1.5-2 meters for air. Thus, from August 17 to August 22, the air and water temperatures were measured in lakes No. 1 and 5. Measurements in the other lakes were conducted once on August 19 and 20, 2023.

Fig. 9 GPS Garmin etrex 20

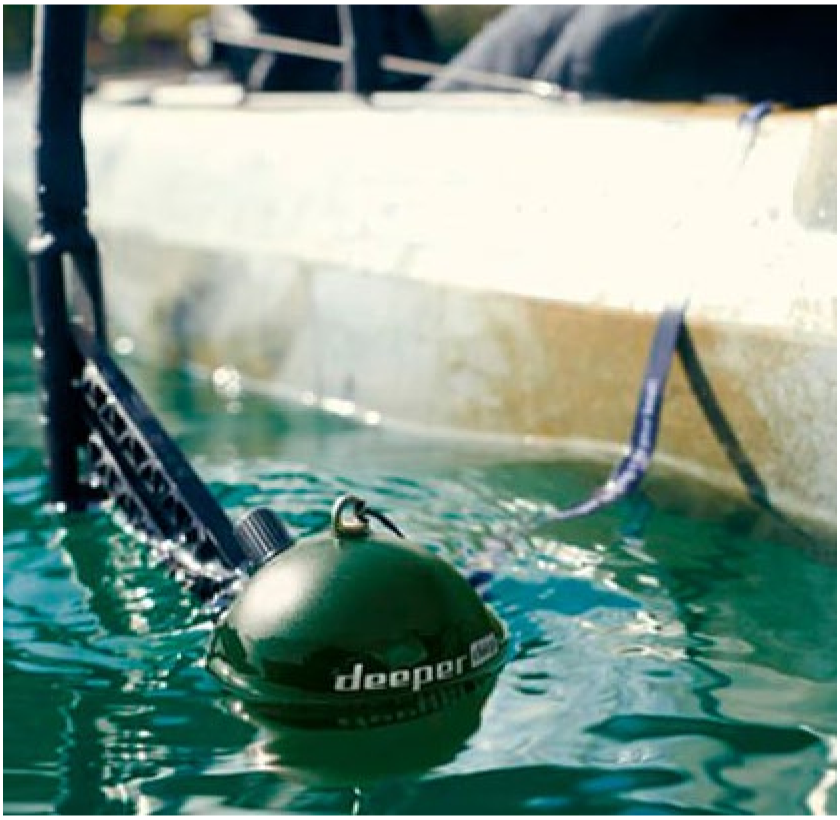


Fig. 10 Echo sounder Fish Deeper chirp+

Fig. 11 Measuring the depth of Lake No. 5 with the Fish Deeper chirp+ echosounder

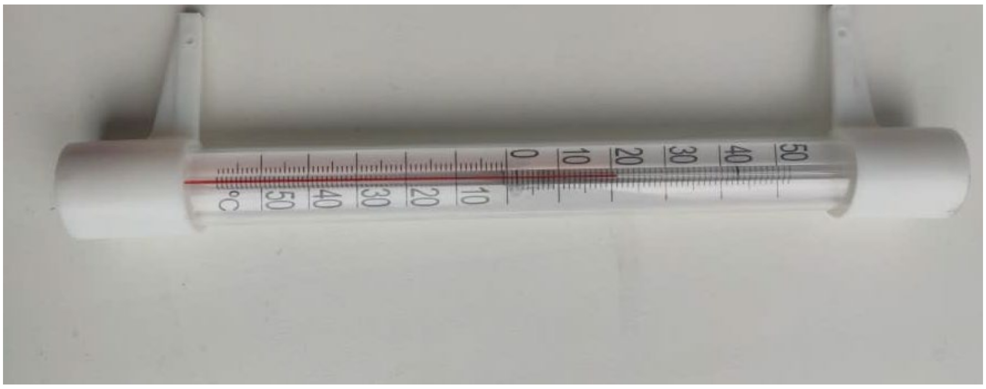


Fig. 12 Alcohol thermometer

Depth measurements were conducted at 7 lakes within the moraine-lake complex of Adygene. To obtain a detailed bathymetric map, measurements were needed along multiple profiles and points to understand the characteristics of the bottom relief of each lake. Therefore, both transverse and longitudinal profiling of water bodies were performed, and their shorelines were determined. Coordinates and depth data were recorded and uploaded using the Fish Deeper-Fishing App software and the Fish Deeper web portal (https://www.fishdeeper.com/).

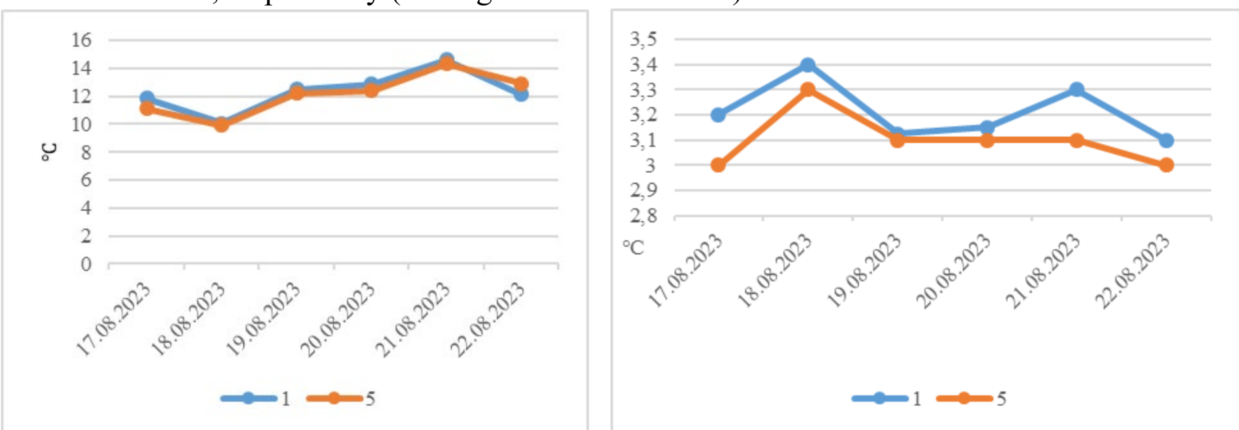
Bathymetric surveys were conducted and bathymetric maps were compiled for 7 out of the 22 lakes. For most of the lakes, such measurements were not performed due to their small surface area and volume, with a maximum depth of about 1 meter (see Figure 13, 14). The bathymetric maps were constructed using interpolation principles with the ArcGIS 10.8 software. To compare the volume and depth of the lakes, the following literary sources were used: for Lake No. 1, data from 2007-2013 and 2017 [4], and for Lake No. 5, data from 2010-2013 [1].

Fig.13 Small lakes № 10,11,12.

Fig. 14 Small shallow lakes № 15, 16

Results of field measurements of air temperature, water temperature and assessment of water turbidity.

From August 17th to August 22nd, the average air temperature near Lake No. 5 was 12.3°C, and near Lake No. 1, it was 12.1°C. However, the average air temperature in the vicinity of these lakes does not differ significantly (see Figure 15). Nevertheless, there is a difference in water temperature between the small lakes, located relatively lower and to the north, where it ranges from 10 to 15°C, and the larger lakes, located at higher absolute altitudes and closer to the glaciers. Water temperature in Lakes No. 1 and No. 5 was lower and practically identical, at 3.2°C and 3.1°C, respectively (see Figure 15 and Table 2).



(a) (b)

Fig. 15 Dynamics of air temperature (a) and water temperature (b) in Lakes No. 1 and No. 5 from August 17 to August 22

Table 2

Air temperature near lakes and water temperature in lakes of the Adygene moraine-lake complex

№ of a lake	Air temperature	Water temperature	Time of measuring
1	20	3,1	15:30
2	19	2,5	19:46
5	19,4	3,2	15:00
7	23	4	16:50
9	20	15	17:00
10	21	14	17:30
11	22	11	16:58
12	21	10	16:59
13	21	10,8	15:50
14	23	13,5	16:35
15	21	17	17:45
16	22	15	17:35
19	22	10	15:14

Lakes Adygene №1,2,5,7, characterized by the lowest water temperature, are directly fed by melt water from glacier No 235 during the observation period. Lakes 11, 12, 13 are located to the north at a lower absolute altitude and have no obvious signs of glacier water inflow in the form of surface streams, but their water temperature is lower than in lakes 9, 10, 15, 16 located even further to the north (Fig. 16). This difference may be due to temporary seasonal glacial water inflow in the form of surface watercourses, which are absent during the observation period, or insignificant glacial water inflow by groundwater. Indirectly, the connection of lakes with intermediate values of water temperature with glacial waters is indicated by the average degree of water turbidity in them, which has an intermediate character relative to other observed lakes.

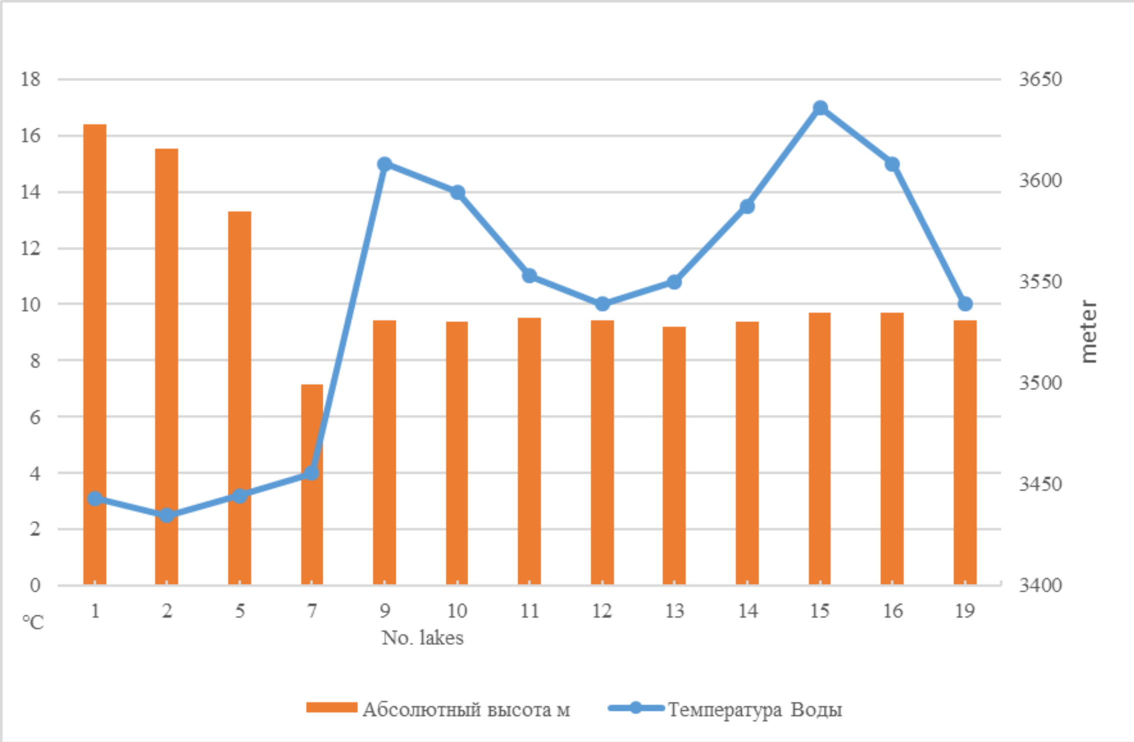


Fig. 16. Water temperature in lakes of the Adygene moraine-glacial complex.

Observations of water turbidity in the studied lakes have shown that the lakes have high, medium turbidity and no turbidity. The degree of turbidity as well as water temperature in the lakes depends on glacier water inflow. Maximum turbidity was determined in lakes 1,2,3,4,5,7 (Fig.17), which during the observation period have a constant supply of glacial melt water. Average turbidity is observed in lakes No.6,8,13,14,15,16,19,20,21,22 (Fig.18,19), where glacial water inflow is presumably of periodic nature due to occurrence of temporary surface watercourses or occurs underground. The accumulation of the lake by a surface watercourse is indicated, as noted above, by the presence of sandy-dusty fine-grained deposits on the shore of Lake No.13. Lakes 9,10,11,12,17 (Fig.20) contain clear water, with almost no turbidity. They may be accumulated by atmospheric precipitation and local surface runoff from the area of the lake depression. In this case, groundwater inflow from moraine deposits is also possible.

17 High turbidity in Lake No. 1 directly fed by Glacier 235

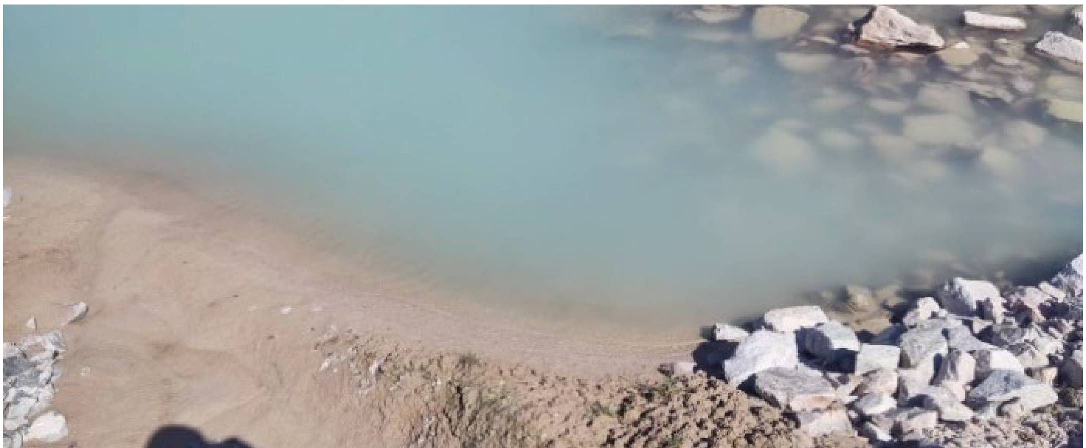


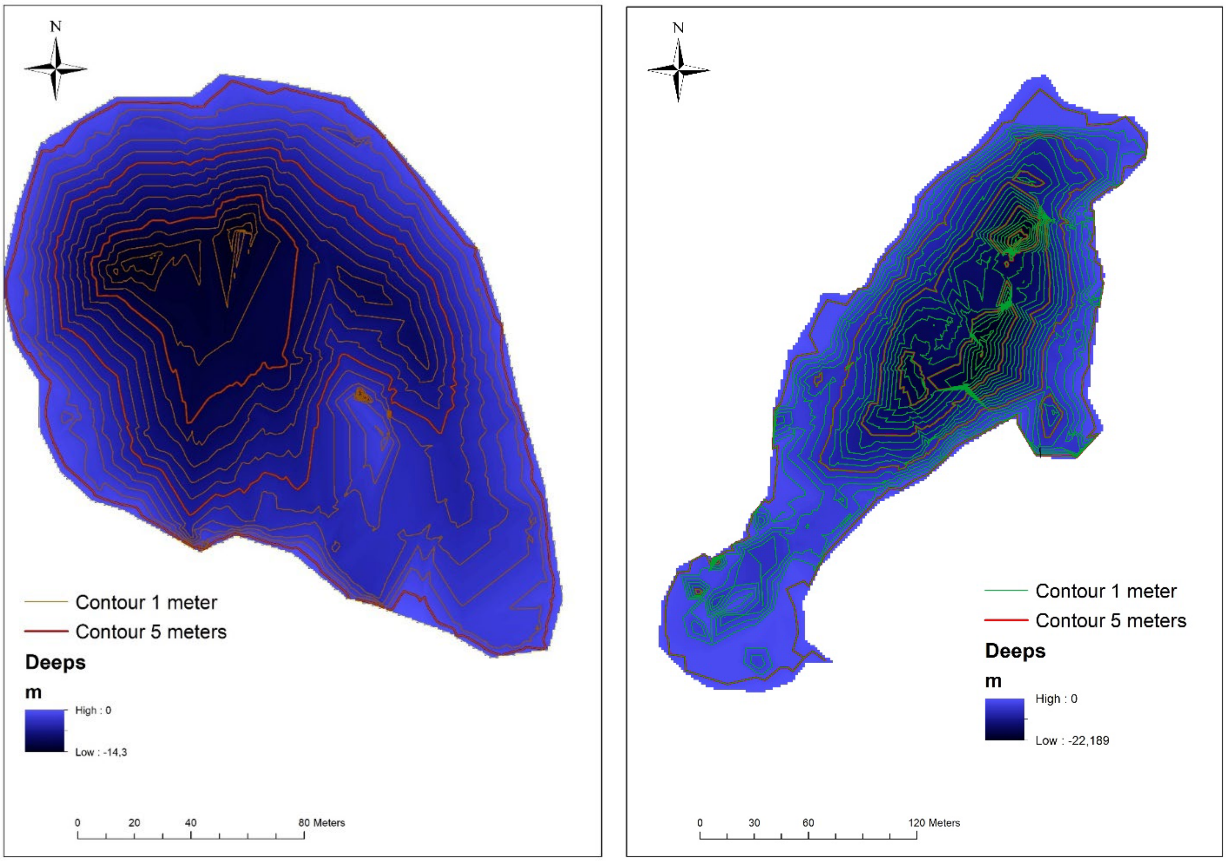
Fig.18 Average degree of turbidity in lake No.13

Fig. 19 Average turbidity in Lake No. 16

Fig. 20 Lake No. 9, with clear water, no turbidity.

Results of bathymetric measurements

Results of bathymetric mapping of lakes 1 and 5 are shown in Figure 21, lakes 2, 7, 13, 14, 19 are shown in Figure 22. In the schemes, darker color indicates greater depth. In lakes № 1,5 the maximum deepest areas are on their northeast and east sides. Lake № 1 has a maximum depth of 14.3 m, with an average depth of 4.9 m, and Lake № 5 has a maximum depth of 22.2 m, with an average depth of 6.5 m. Lakes № 1, 5 have an area of 0.0255 km^2 and 0.035 km^2, respectively. The volume of water in the lakes is 145 000 m^3 and 213 000 m^3, respectively. Data on lakes 2,7, 13,14,19 are given in Table 3 and shown in Figure 23.



(a) (b)

Fig. 21. Bathymetric maps of Lakes 1(a) and 5(b)

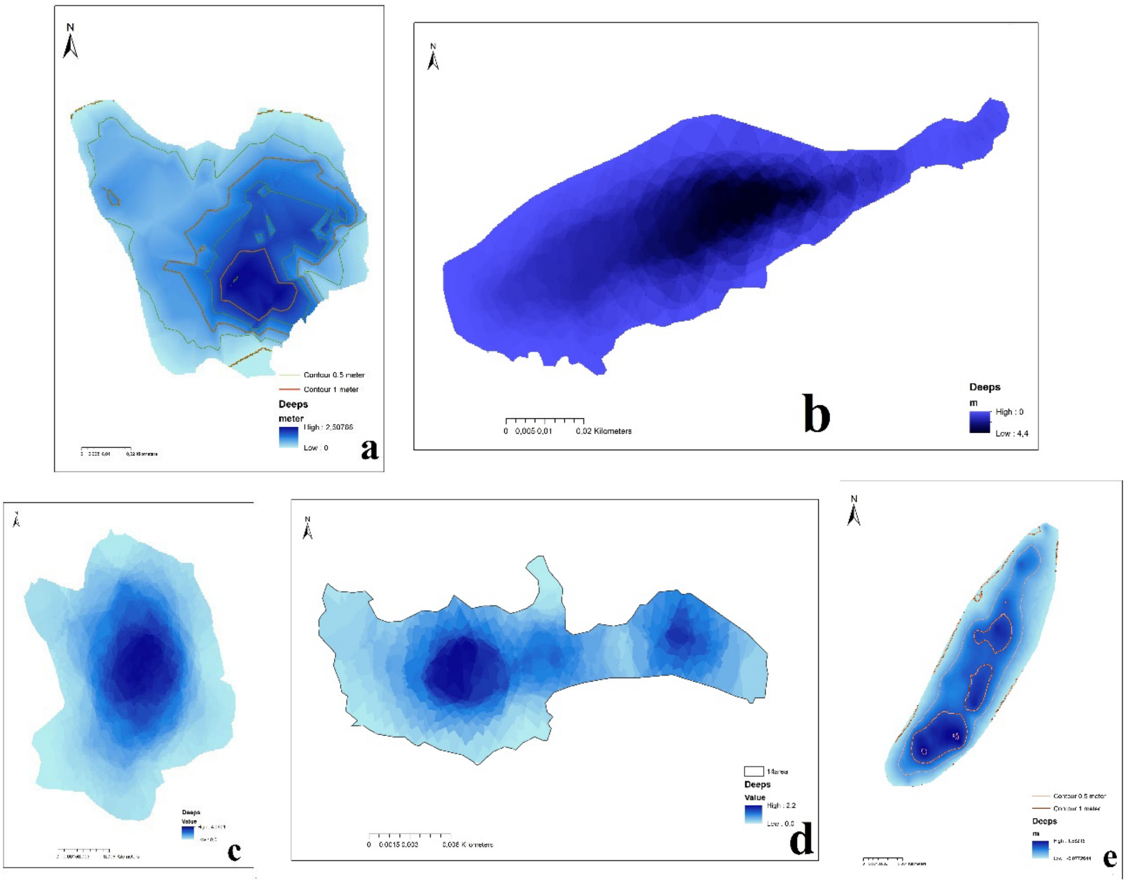
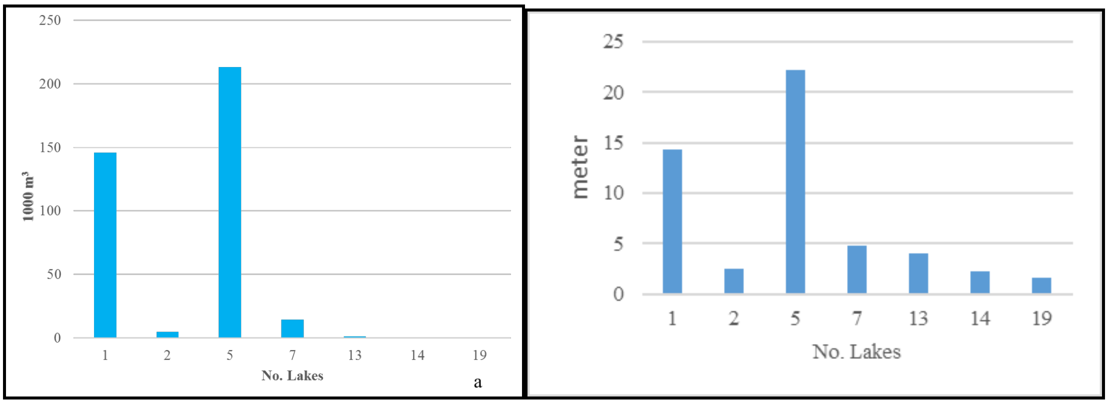


Fig. 22. Bathymetric maps of lakes 2(a), 7(b), 13(c), 14(d), and 19(e)

Table 3.

Bathymetric data of some lakes of the Adygene moraine-lake complex

№ of a lake	Average depth of lakes (m)	Maximum depth of lakes (m)	Water volume (thousand m^3)	Time of measuring
1	4,9	14,3	145,8	20/08/2023
2	0,8	2,5	4,9	20/08/2023
5	6,5	22.2	213	20/08/2023
7	1,1	4,8	14,5	19/08/2023
13	1,3	4,1	1,3	19/08/2023
14	0,8	2,2	0,4	19/08/2023
19	0,5	1,6	0,06	19/08/2023



(a) (b)

Fig. 23 Bathymetric parameters of some lakes of the Adygene moraine-lake complex: water volume (a) and maximum water depth (b).

Clarification of the structure of glacier No. 235

During the fieldwork, the origin and structure of the moraine section located at the terminus of Glacier No. 235 were clarified. It was determined that this section (marked by the red arrow in Figure 24) is formed by a protrusion of the bedrock, partially covered by clastic moraine rocks, as shown in Figure 25. Additionally, using angle measurements, the maximum height of the ice ledge at the terminus of Glacier No. 235 (marked by the blue arrow in Figure 24) was determined to be 6.5-7 meters as of August 2023 (Figure 26).

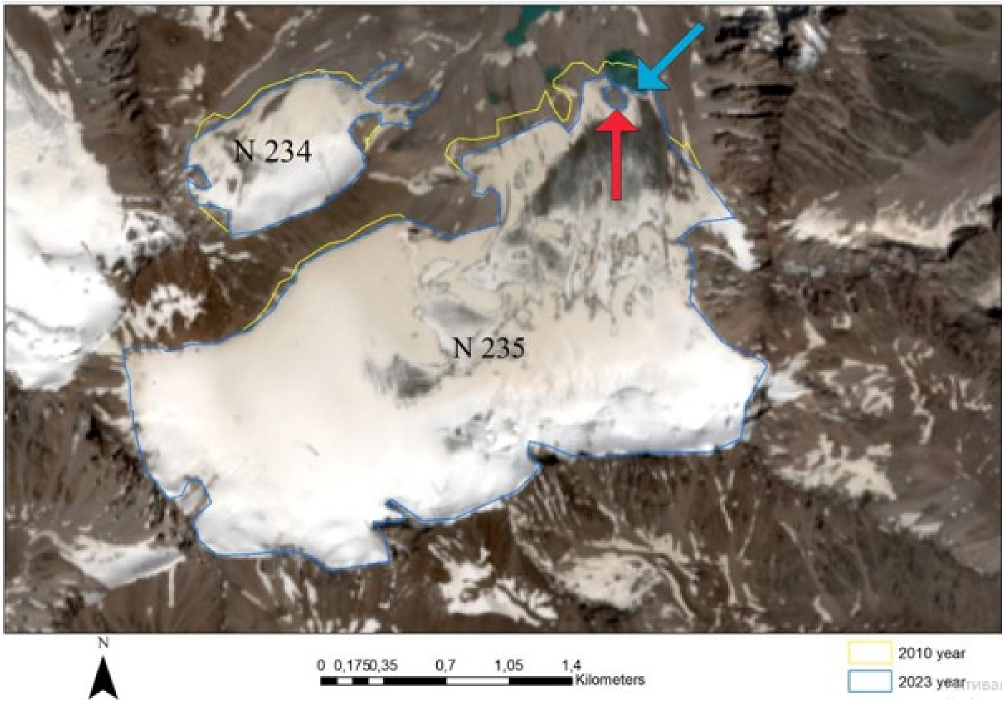


Fig. 24. Scheme of the location of observation objects on Glacier No. 235. Red arrow - rocky basement ledge at the terminus of Glacier 235. Blue arrow - location of the ice cliff on the tongue of Glacier 235.

Fig. 25 Outcrop of bedrock at the terminus of Glacier No. 235

Fig. 26 Ice cliff at the terminus of glacier № 235

Conclusion

The moraine-glacier-lake complex of Adygine is characterized by varying dimensions of its constituent rocky debris, with a predominance of large fractions and a sandy-dusty aggregate. Different age generations of the complex have different thicknesses and specific spatial distributions, which result in a ridged and hilly relief of the moraine complex, and ultimately, the formation of relatively small temporary or relatively permanent lakes.

Thus, on the surface of the Adygine moraine complex, up to the retreating terminus of the glacier tongue, dozens of small water bodies and relatively large lakes are formed or are forming. Overall, they can be grouped into two categories of lakes. The first group consists of small lakes in terms of size, located in the lower part of the moraine complex; they are relatively old in terms of formation age and stable. The second group of lakes is located in the upper part of the complex; they formed relatively recently, and for some of them, the lake formation process is ongoing as they develop following the retreating glacier. These lakes are much larger in terms of area, depth, and volume compared to lakes in the first group. The distinctive feature of the second group of lakes is their dynamic nature. While the first group of lakes is more stable against various changes, the second group of lakes is less resistant to both internal and external factors of change. The risk of glacial lake outburst floods is primarily associated with the second group of lakes.

The results of field studies have provided new information on the nature of formation, development and current functioning of lakes of the Adygene moraine-glacial complex. The results of measurements of lake depths, water and air temperatures, observations of the lithological composition of moraine sediments of lake dams allow us to clarify the mechanism of possible lake outburst and the associated degree of risk.

References

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Appendix.

Small lakes of the Adygene moraine-lake complex

Date of observation: 19.08.2023 г

Lake name: No. 19
Measuring time: 15:14
Coordinates: 42,51593N, 074,43987 E
Air temperature: 22° C
Water temperature: 10°C
Photo position: from the eastern side
Water in the lake: clear
Bathymetric measurement: completed

Lake No. 19 (Photo position: east side)

Lake name: № 13
Measuring time: 15:50
Coordinates: 42.51621204° N, 74.44089326° E
Air temperature: 21° C
Water temperature: 10,8°C
Photo position: from the west side
Water in the lake: medium turbidity, in some places deposits of fine-grained sediment up to 0.4 m thick.
Bathymetric measurement: completed

Lake No. 13 (Photo position: from the west side)

Lake name: #14
Measuring time: 16:35
Coordinates: N42,51676, E074,44132
Air temperature: 23°C
Water temperature: 13,5°C
Photo position: from the eastern side
Water on the lake: slightly turbid
Bathymetric measurement: completed

Lake No. 14 (Photo position: east side)

Lake name: No. 7
Measuring time: 16:50
Coordinates: 42.51444314° N, 74.44131838° E
Air temperature: 23° C
Water temperature: 4°C
Photo position: from the west side
Water on the lake: turbid
Bathymetric measurement: completed


Lake No. 7 (Photo position: from the west side)

Lake name: No. 11
Measuring time: 16:58
Coordinates: 42.51671606° N, 74.44299792° E
Air temperature: 22° C
Water temperature: 11°C
Photo position: east side
Water on the lake: clear
Bathymetric measurement: not conducted

Lake No. 11 (Photo position: east side)

Lake name: No. 12
Measuring time: 16:59
Coordinates: 42.51660146° N, 74.44244717° E
Air temperature: 21° C
Water temperature: 10°C
Photo position: east side
Lake water: clear
Bathymetric measurement: not conducted

Lake No. 12 (Photo position: east side)

Lake name: No. 9
Measuring time: 17:00
Coordinates: N42,51711, E74,44154
Air temperature: 20°C
Water temperature: 15°C
Photo position: from the western side
Water on the lake: clear
Bathymetric measurement: not conducted

Lake No. 9 (Photo position: from the west side)

Lake name: No. 10
Measuring time: 17:30
Coordinates: N42,51766, E 74,44284
Air temperature: 21° C
Water temperature: 14°C
Photo position: from the north side
Water on the lake: clear
Bathymetric measurement: not conducted

Lake No. 10 (Photo position: north side)

Lake name: No. 16
Measuring time: 17:35
Coordinates: N42,51851, E074,44231
Air temperature: 22° C
Water temperature: 15°C
Photo position: from the south side
Water on the lake: slightly turbid
Bathymetric measurement: not conducted

Lake No. 16 (Photo position: south side)

Lake name: No. 15
Measuring time: 17:45
Coordinates: N42,51851, E074,44231
Air temperature: 21°C
Water temperature: 17°C
Photo position: from the south side
Water in the lake: clear
Bathymetric measurement: not conducted

Lake No. 15 (Photo position: south side)