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SNOW COVER AND GLACIERS

DYNAMICS OF LAKES OF THE BOLSHOY AZAU GLACIER ON ELBRUS

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High rates of degradation of the Bolshoy Azau Glacier on Elbrus make it necessary to assess the development of lakes on the ice-free land and on the glacier itself. For this purpose, aerospace data for the period of 1957–2021, as well as information from visual observations, Internet sources, and tourist photos were analyzed. The existence of 15 lakes with an area of 140–20 250 m^2 on the Bolshoy Azau Glacier and the adjacent territory was recorded at various times. The long-term existence of the lake in contact with the glacier on the Echo of the War mountain passage covering with an area of up to 4500 m^2 was revealed for the period of 1971–2009. The maximum area (20 250 m^2) was detected on a satellite image from June 25, 2009 for a lake on the dead ice part of the median moraine between left and right ice streams of the Bolshoy Azau Glacier. In the hollows on the glacier surface, up to three lakes with a maximum total area of 7860 m^2 were observed in different times. Lakes on the Bolshoy Azau Glacier appeared mainly during the snow cover melting, while masses of drifted snow served as dams in the drainage area of hollows. These lakes disappeared after melting of drifted snow dams and/or in the course of drainage through subglacial and underground runoff channels.

Keywords: *glacier, satellite images, glacial lake, drainage channel, snow cover, lake basin.*

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INTRODUCTION

Climate warming and succeeding degradation of glaciers induce the formation on new lakes posing a significant risk of outbursts and floods that may led to natural disasters with a large number of human casualties – up to 4000–6000 people [*Allen et al., 2016; Mergili et al., 2020*]. According to [*Emmer, 2018*], 892 scientific papers on the subject of lake outbursts were recorded in the Web of Science database for the period of 1979–2016. One of the recent examples is an outburst of Lake Bashkara in the Caucasus that led to the catastrophe in 2017 [*Chernomorets et al., 2018*].

The other instances happened to the lakes that were formed in front of the Elbrus glaciers. They repeatedly broke through in the upper reaches of the Birdzhalysu River in 1909, 1973, 1983, 1993, 1999, 2003, and 2006 [*Gerasimov, 1909; Chernomorets et al., 2007; Dokukin et al., 2012, 2022*]; in the upper reaches of the Garabashi River Azau Basin in 1895 [*Ivanov, 1902*], in 1912, and 1947; and in the upper reaches of the Malaya Azau River in 1978 and 2011 [*Seynova, Zolotarev, 2001; Dokukin et al., 2016*].

The rate of degradation of the Elbrus glaciers has increased significantly in the 21st century [*Kutuzov et al., 2019; Bekkiev et al., 2021*]. Significant risks of emergence and outburst of lakes in front of the Bolshoy Azau Glacier were discussed by Vasil'chuk with coauthors [*Vasil'chuk et al., 2010*]. In order to estimate the scale and rate of lake formation on the ice-free land of the Bolshoy Azau Glacier and on the glacier itself, multitemporal satellite images and available data of aerial surveys, Internet data, information and photos from travelers were analyzed.

MATERIALS AND METHODS

Aerial photos, satellite images, topographic maps and orthophotomaps, photos from helicopter, and ground photos of various authors were used in our study (Table 1).

Satellite images and aerial photos were transformed using SPLINE transformation and reference points to the WGS 84 coordinate system in the UTM zone 38N in the ArcMap 10.7 program; lakes were vectorized, and their areas were determined. Measurement errors were estimated via triple delineation of the lakes. On the Sentinel-2 and Landsat 5-8 satellite images, the lakes were more clearly displayed using false color (false color, bands 8, 4, 3). Depending on the characteristics of satellite images, the clarity of

Table 1. **Materials used**

Materials	Year/Data	Scale, resolution, m (MS/Panchromatic)	Source, copyright holder
Aerial photographs	Aug. 22, 1957; Sept. 8, 1973, 1975; Aug. 17, 1983; July 27, 1988	1:25 000	Archive of the Federal State Budgetary Institution "High Mountain Geophysical Institute"
Topographic maps	1958	1:10 000	*Atlas of Elbrus Glaciers*. [*1965*]
	2012	1:5000	Aerotech JSC
Orthophotomaps	1997	1:10 000	I.A. Labutina, E.A. Zolotarev et al.
	Sept. 28, 2012	1:5000	Aerotech JSC
Satellite images			
KH-4B (Corona)	Sept. 20, 1971	1.8	Site EarthExplorer [https://earthexplorer.usgs.gov/]
Landsat 7	Aug. 9, 1999; Sept. 12, 2000	30/15	
IRS P5	Sept. 12, 2007	2.5	© 2003-2007 ANTRIX
IRS 1C/1D	Aug. 1, 2006; Aug. 11, 2006	23/5.8	© 2006 National Remote Sensing Centre, Department of Space, Government of India
EROS A	July 20, 2007	1.8	© 2007 ImageSat International N.V.
SPOT 5	Sept. 21, 2011	10/2.5	© CNES 2011
GeoEye-1[6]	Sept. 19, 2009; Oct. 16, 2009; Sept. 23, 2014	1.64/0.41	© GeoEye, Inc.
GeoEye-1	Feb. 15, 2014; Sept. 12, 2015	1.64/0.41	World Imagery [http://goto.arcgisonline.com/maps/World_Imagery]
WorldView2	Aug. 31, 2010	1.84/0.46	
Pleiades-1A	Sept. 6, 2014	2/0.5	© CNES 2014
Pleiades-1B	Aug. 23,2015		© CNES 2015
Sentinel-2	**2015–2021**	20/10	Site Sentinel Hub EO Browser [https://apps.sentinel-hub.com/eo-browser/]
Landsat-5	**2009**	82/30	
Landsat-8	**2013–2015**	30/15	
Resurs P	Aug. 19. 2016	3/1	Research Center for Space Hydrometeorology "PLANETA"
Kanopus B5	Sept. 15, 2020	10.5/2.1	
Ground photographs	Aug. 29, 1973; July 1985; Aug. 27, 2008; June 7, 2020	– – – –	V.F. Sukomeilo; uz89 [https://risk.ru/blog/198343]; A. Lebedev; K. Lagodienko
	2009–2012	–	Ya. Berezhko
Helicopter photos	June 18, 2009; June 17, 2011; June 23, 2015	–	M.D. Dokukin

Note: MS, multispectral images. Images from IRS, EROS, SPOT, GeoEye, and Pleiades satellite were kindly provided by the SCANEX Engineering and Technology Center. Dashes mean that the photos were made with different models of digital and SLR cameras.

coastlines, and the shape of the lakes, the measurement errors varied from 1 to 33% (mostly, up to 10%). The absolute heights of the lakes were determined according to the topographic map of 2012 on a scale of 1:5000.

The comparative interpretation of multitemporal images was carried out using the Swipe Layer tool for interactive display of multitemporal layers in the ArcMap program and in the GIF animation mode of the Easy GIF Animator Pro to reveal changes in the state of lakes and their basins, identify areas of dead ice, and determine glacier boundaries.

RESULTS

According to [*Bekkiev et al., 2021*], the area of the Bolshoy Azau Glacier decreased by 6.35 km^2 from 1957 to 2020, taking into account the reduction of the tongue of the glacier descending into the Ulukam River valley. In 2011–2021, the decrease in the area of the Bolshoy Azau Glacier, including areas on the border of the Bolshoy and Maly Azau Glaciers, amounted to 2.21 km^2 (almost 35% of the total area loss for 1957–2021). To the western and central areas of maximum deglaciation, the area of the formed massif of dead ice from the middle moraines was added. It

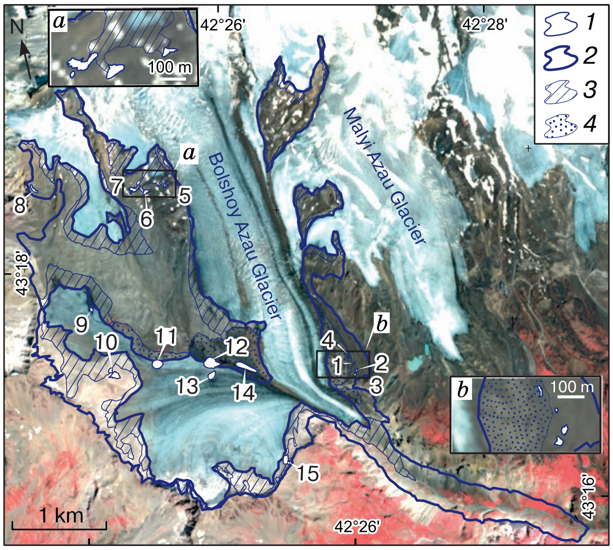

Fig. 1. Degradation of the Bolshoy Azau Glacier for 1957–2021 and formed lakes on Sentinel-2 image from August 27, 2021:

(*a*) Enlarged fragment of the north lakes area; (*b*) enlarged fragment of the east lakes area. Lake numbers are given in Table 2. *1* – lakes, *2* – areas freed from ice in 1957–2021, *3* – ice-free areas in 2011–2021, *4* – dead ice.

was identified from the absence of ice movement during the analysis of glacier dynamics in ArcMap and GIF animations.

Figure 1 shows the zones of deglaciation and lakes that existed in different periods in these areas and on the Bolshoy Azau Glacier itself. A total of 15 lakes were identified: 4 lakes in the eastern section, 4 lakes in the northern section, 6 lakes in the Khotyutau Circus and in the section of median moraines, and 1 lake at the Echo of War Pass. The characteristics of the lakes are presented in Table 2.

Table 2. **Characteristics of lakes of the Bolshoy Azau Glacier**

No.	Coordinates	Height, m a.s.l.	Maximum area, thousand m^2	Date
		East lakes		
1	N43°17′07,89″ E42°26′22,54″	3251	0.14 ± 0.012	Sept. 19, 2009
2	N43°17′05,07″ E42°26′22,97″	3247	0.59 ± 0.03	Aug. 31, 2010
3	N43°17′04,02″ E42°26′21,71″	3244	0.67 ± 0.007	June 23, 2015
4	N43°17′10,81″ E42°26′20,80″	3262	0.41 ± 0.010	Sept. 15, 2020
		North lakes		
5	N43°18′20,46″ E42°25′11,30″	3637	1.12 ± 0.07	Sept. 12, 2015
6	N43°18′19,64″ E42°25′02,18″	3637	2.43 ± 0.024	Sept. 28, 2012
7	N43°18′20,97″ E42°24′57,12″	3638	3.86 ± 0.10 0.43 ± 0.041	Sept. 12, 2015
8	N43°18′28,09″ E42°24′10,25″	3600	2.20 ± 0.18	Aug. 27, 2021
		Lakes in the Khotyutau Circus and the massif of median moraines		
9	N43°17′43,11″ E42°24′25,79″	3385	2.56 ± 0.55	June 7, 2017
10	N43°17′21,30″ E42°24′30,05″	3349	3.50 ± 0.15	July 20, 2007
11	N43°17′20,31″ E42°24′50,83″	3260	7.96 ± 0.97	June 19, 2016
12	N43°17′18,51″ E42°25′16,60″	3250–3255	20.25 ± 1.03	June 25, 2009
13	N43°17′13,99″ E42°25′14,97″	3255–3260	6.28 ± 1.02	June 2, 2019
14	N43°17′13,55″ E42°25′31,03″	3255	14.92 ± 5.01	June 19, 2016
		Lake on the Echo of War Passage		
15	N43°16′40,32″ E42°25′41,90″	3315	4.54 ± 0.07	July 20, 2007

East Lakes (nos. 1–4)

The lakes appeared following the retreat of the left edge of the glacier in the 21st century depressions of the initial relief covered with moraine. The first mention about these lakes and their photos of 2008 were received from A. Lebedev. Because of their size, ultrahigh resolution satellite images were used to study their dynamics (Fig. 2).

A specific feature of the dynamics of these lakes is the disappearance of Lake 2 in the second half of September (Fig. 2*b*, September 19, 2009; Fig. 2*d*, September 23, 2014) despite its presence in August and the beginning of September (Fig. 2*c*, August 31, 2010; Fig. 2*e*, August 23, 2015).

One of the explanations is that the main water flow from the glacier passes beyond Lake 2 and enters the basin due to channel branching during the maximum water level in July–August. In that period, the area of the lake reached 600 m^2. However, in late August–early September, a light-colored strip appeared on satellite images near the lake indicating a decrease in the water level. Lake 2 was clearly seen on images of 2016–2019 and was not seen on images of 2020–2021. In 2014–2015, water stopped flowing into the basin of Lake 1, which had already been filled with glaciofluvial sediments by that time.

Lake 3 was identified from an indirect sign – the appearance of a light-colored area on the image of 2015 in place, where no indication of the lake existence could be found in previous years (Fig. 2*e*). The existence of Lake 3 was confirmed by data of a helicopter flight on June 23, 2015: in this place, a reservoir with numerous ice floes was seen in the depression covered with snow. In subsequent years, Lake 3 could be seen on Sentinel-2 images made during the

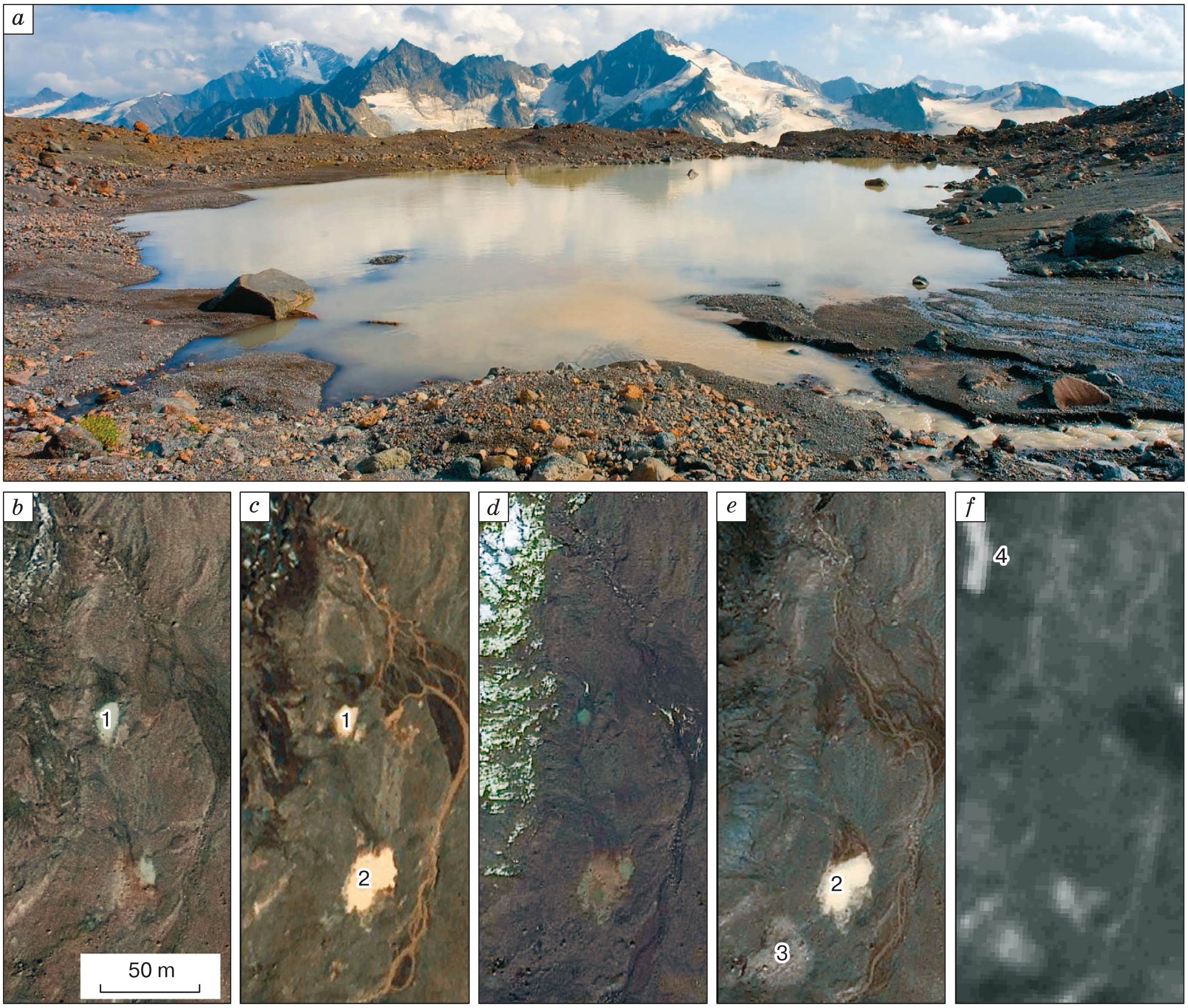

Fig. 2. Lakes to the east of the Bolshoy Azau Glacier:

(*a*) Lake 2, photo by A. Lebedev (Aug. 27, 2008); satellite images: (*b*) GeoEye-1 (Sept. 19, 2009), (*c*) WorldView2 (Aug. 31. 2010), (*d*) GeoEye-1 (Sept. 23, 2014), (*e*) Pleiades (Aug. 23, 2015), and (*f*) Canopus B5 (Sept. 15, 2020). Lake numbers correspond to Fig. 1 and Table 2.

snowmelt season in June–early July. Lake 4 appeared on the site of dead ice in 2020 and was still present in 2021 (Fig. 2*f*).

North Lakes (nos. 5–8)

The dynamics of the North lakes are shown in Fig. 3, and their areas are presented in Table 2. The formation of the lakes began in 2007 following the retreat of the glacier from the territory of the lava flow; several local depressions formed on its surface. By 2012, the glacier and dead ice partially covered basins of lakes 5 and 7 (Fig. 3*a*). By that year, Lake 6 had reached its maximum area. In 2015, lakes 5 and 7 reached their maximum sizes (Fig. 3*c*). However, Lake 6 disappeared after the water inflow from the glacier discontinues because of changes in the local landscape features.

At the same time, the satellite image from February 2014 (Fig. 3*b*) shows that all these lakes were absent in winter, which can be explained by the underground runoff from the lakes as noted in [*Dokukin, Shagin, 2014*].

The area of Lake 5 changed little during summer seasons until 2021. Just the opposite, lake 7 experienced considerable fluctuations; thus, in August 2019 and 2020, its area decreased from 3900 to 1100–1200 m^2. This can be explained by the fact that the main runoff from the glacier no longer fell into the basin. This lake is fed by two residual glaciers, the runoff from which into the lake at the end of summer becomes lower than the outflow from the lake through underground channels.

At the end of August 2021, there were still snowfields on the site of the lakes, and they were melting and kept feeding Lake 7 at a high level. The area of the lake began to decrease gradually after September 4, 2021 as a result of cooling and decreased sharply only at the end of September. The same rapid reduction in area was observed in the second half of August 2020 for Lake 8, which formed in the 1980s.

Lakes in the Hotyutau circus and on the massif of median moraines (nos. 9–14)

Lake 9 was identified on a photo by an unknown author dated 1991. The lake was recorded on the surface of the Bolshoy Azau Glacier during the flight on June 17, 2011 and on satellite images in subsequent years at the beginning of summer. Below the lake basin, there is a permanent channel developed by the water flow on the surface of the glacier.

Lake 10 appeared on the surface of the bedrock (crossbar) covered by moraine following the retreat of the glacier to the lower levels. The dynamics of the lake was studied using high and ultrahigh resolution images (Fig. 4).

Comparison of satellite images with the topographic map (scale 1:5000) showed that the water level in the lake decreased by 5 m in the period from 2007 to 2012. In 2007, the maximum depth of the lake was 3.5 m. The glacier dammed the lake from the northwestern side. In 2007, the surface flow from the lake towards southeast was formed. As the glacier retreated, the lake continued to exist, but the surface flow from it stopped.

Comparison between the helicopter image made on June 17, 2011 (Fig. 4*d*) and the satellite image from September 21, 2011 demonstrated a sharp decrease in the area from 3210 to 1750 m^2 in 2011, when arc cracks appeared on the surface of the glacier and the lake water level dropped by 4 m. Such cracks indicate that there was a grotto filled with lake water under the surface of the glacier, the roof of which then collapsed. Subsequently, the remaining small lake existed until 2015 (area 1000 m^2 on September 12, 2015) and then disappeared.

Lake 11 was recorded on a satellite image from July 20, 2007 (Fig. 5*a*); its boundaries were identified on a helicopter image from June 17, 2011 (Fig. 5*d*).

On satellite images of 2013–2015, this lake could not be identified. In 2016, the lake appeared on May 30 and reached its maximum area of about 8000 m^2 on June 19–22 (Fig. 5*b*). Then, the lake considerably shrunk and disappeared by the early July. In 2017 and 2018, it existed for a short time and its area was less than 100–200 m^2. In 2019, the lake existed in May with an area of up to 2000 m^2; in June, its area was minimal (Fig. 5*c*). In 2020 and 2021, the lake was absent.

Lake 12 formed in a thermokarst funnel in the area of dead ice in the massif of median moraines (Fig. 6).

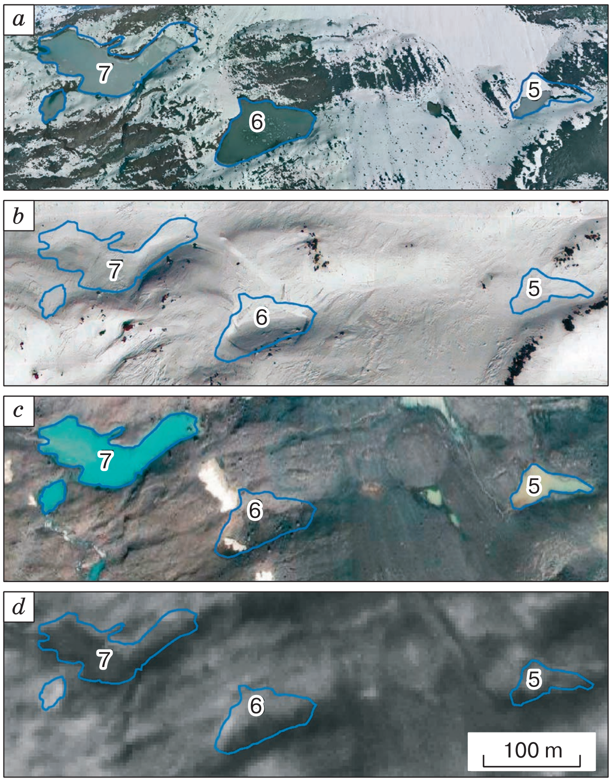

Fig. 3. North group of lakes:

(*a*) Aerial photo from Aerotech JSC (Sept. 28, 2012), (*b*) GeoEye-1 image (Feb. 15, 2014), (*c*) GeoEye-1 image (Dec. 9, 2015), and (*d*) Canopus B5 image (Sept. 15, 2020). Boundaries of lakes 5 and 7 are drawn according to data of 2015; boundaries of Lake 6 are drawn according to data of 2012.

On the satellite image from July 20, 2007 (Fig. 6*c*), traces of lake 12 were seen as an oval-shaped line on the snow-covered surface of the glacier. The lake was identified during the flight on June 18, 2009 (Fig. 6*a*). Its area exceeded 12 000 m^2. The maximum area of the lake was found on the Landsat-5 image from June 25, 2009; it reached 20 000 m^2 (Fig. 6*d*). On the photo from June 17, 2011 and on the satellite image from September 21, 2011, this lake was no longer found (Figs. 6*b* and 6*e*).

A comparison between two satellite images from August 11, 2006 (5.8 m resolution) and September 19, 2009 revealed similar features of a thermokarst funnel with fresh edges and walls, which suggests that the lake already existed in 2006. A clear boundary is visible on the snow-covered sections of the funnel walls on the helicopter image from June 17, 2011 (Fig. 6*b*); it can be interpreted as a fresh trace of the existence of the lake. The lake was clearly identified on satellite images from May 28 and June 13, 2013; its area was more than 12 000 m^2 (Fig. 6*f*). According to the contour line of the lake on the topographic map of 2012, the volume of the lake in 2013

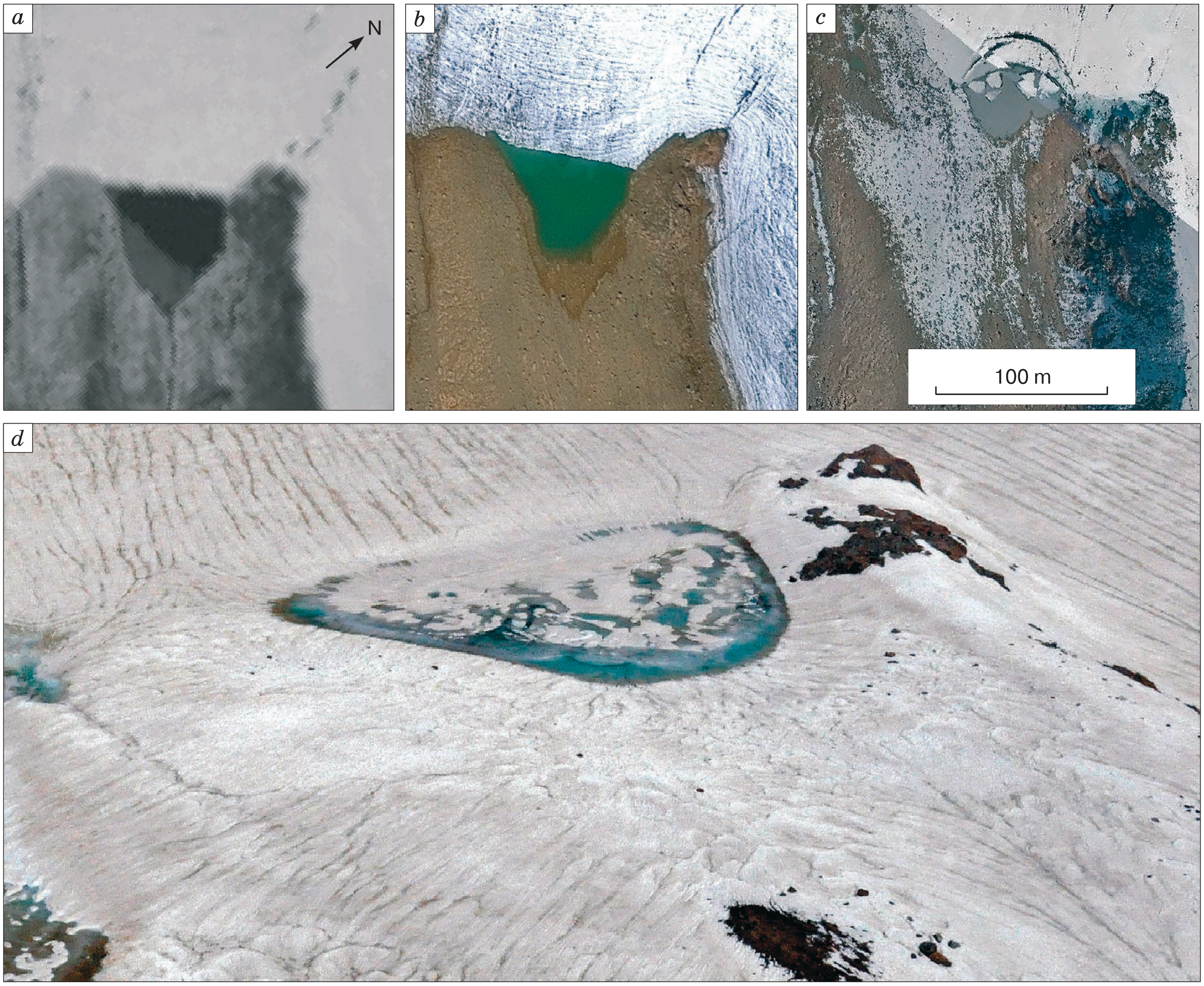

Fig. 4. Lake 10 at the rock bar in the Khotyutau Circus:

(*a*) EROS A image (July 20, 2007), (*b*) GeoEye-1 image (Sept. 19, 2009), (*c*) aerial photo from Aerotech JSC (Sept. 28, 2012), and (*d*) photo by M.D. Dokukin (June 17, 2011).

was estimated at about 52 000 m^3; the depth was up to 15–17 m. At the end of June 2013, the lake disappeared. It appeared again in June 2017 and existed throughout June. It covered an area of 8400 m^2 on June 2. Much smaller lake area (<4000 m^2) was observed on June 2, 2019. In subsequent years, Lake 12 did not appear on the analyzed materials.

A depression on the glacier surface in the area of Lake 13 began forming in 2017. The first lake with an area of less than 1000 m^2 appeared in June 2018. In 2019, the lake of the same area appeared on May 13 and began expanding. By the end of May, the area of the lake covered with ice floes reached 6300 m^2 (Fig. 5*c*).

The size of the lake did not change throughout June. Then, with the release of the glacier from snow, the area of the lake decreased to 2000–2200 m^2. The lake existed on the surface of the glacier until the middle of September 2019. In 2020, it existed from the end of May until July 25 without considerable fluctuations in size (about 3300 m^2). In 2021, despite the increase in the depression, the area of the lake did not exceed 2000 m^2 from the end of May to the end of June (Fig. 5*e*).

Lake 14, about 200 m long, was identified on a satellite image from May 31, 2014. In 2015, the boundaries of the lake could be hardly observed. In 2016, the lake existed in June; on June 19, its area reached 14 920 m^2 with a length of 300 m and a width of 50 m (Fig. 5*b*). At the end of June, the lake disappeared. In 2017, the lake appeared on May 8 and had a length of 150 m. In late May–early June 2017, the lake reached its usual size (length 240 m) and disappeared in early July. On May 3, 2018, the lake was

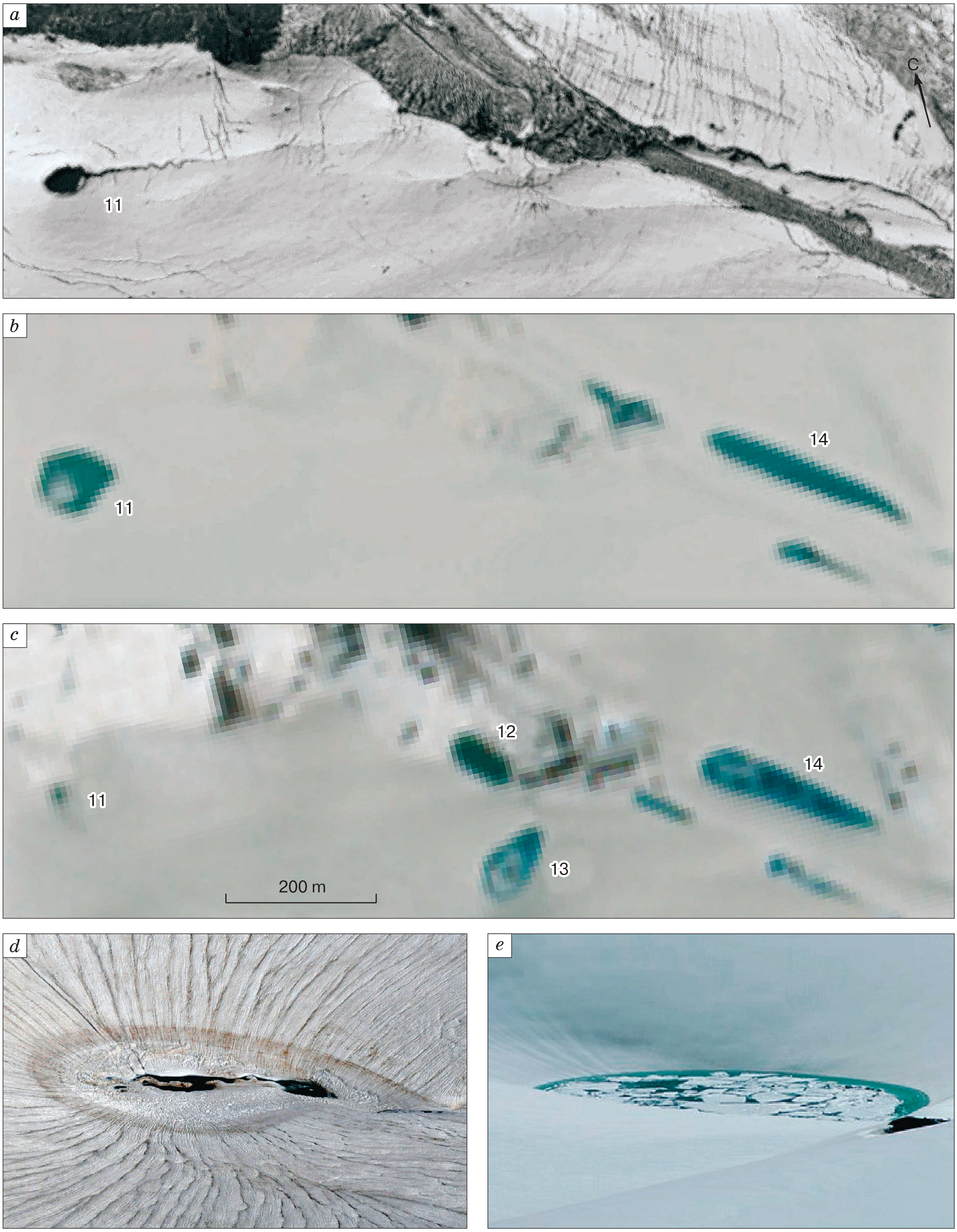

Fig. 5. Lakes on the Bolshoy Azau Glacier and on the dead ice massif of median moraines:

(*a*) EROS A image (June 20, 2007), (*b*) Sentinel-2 image (June 19, 2016), (*c*) Sentinel-2 image (June 2, 2019), (*d*) traces of Lake 11, photo by M.D. Dokukin (June 17, 2011), and (*e*) Lake 13, photo by K. Lagodienko (June 7, 2020).

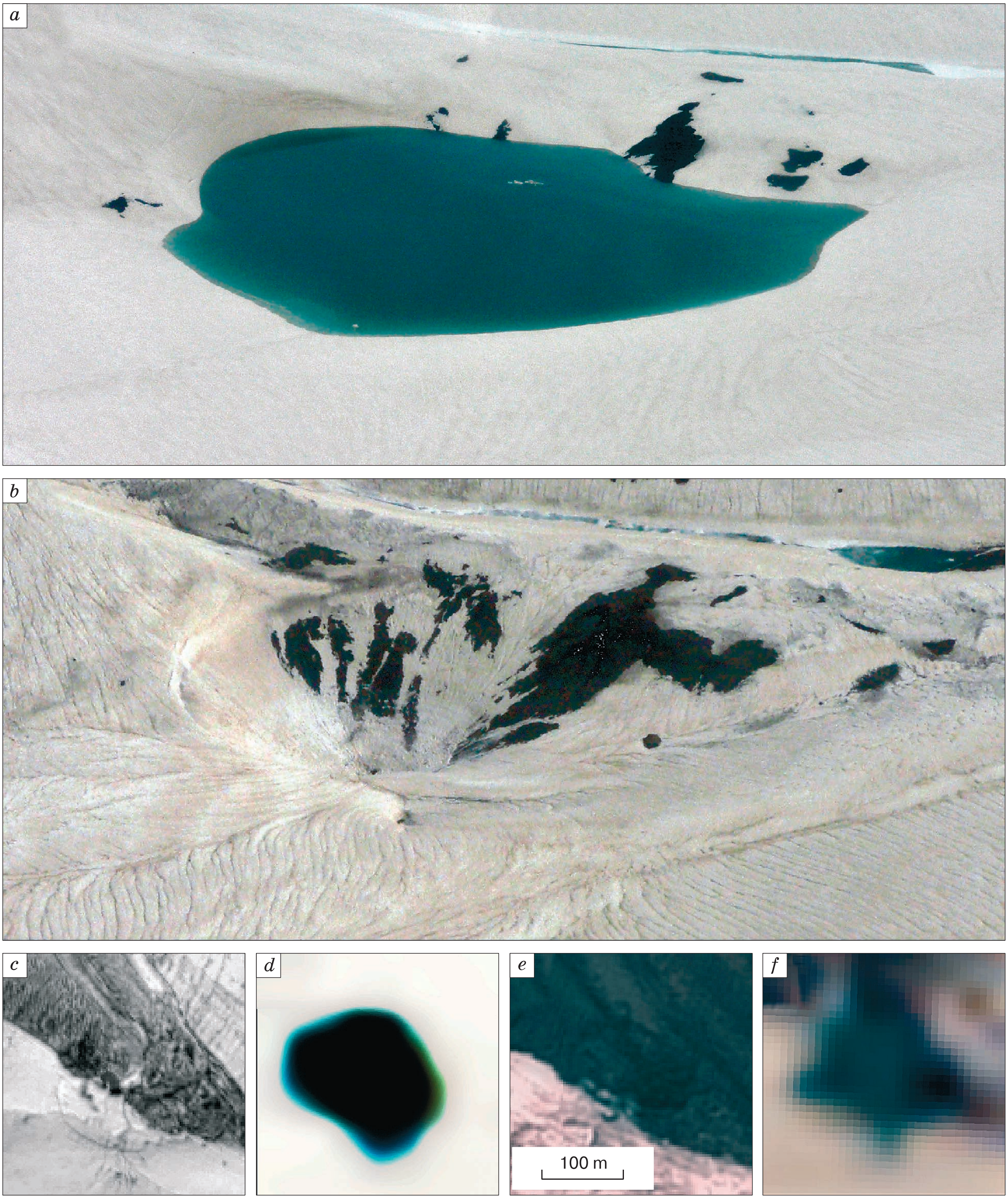

Fig. 6. Lake 12 on a massif of dead ice of median moraines:

(*a*) Photo by M.D. Dokukin (June 18, 2009), (*b*) photo by M.D. Dokukin (June 17, 2011), (*c*) EROS A satellite image (June 20, 2007), (*d*) Landsat-5 image (June 25, 2009), (*e*) SPOT 5 image (Sept. 21, 2011), and (*f*) Landsat-8 image (June 13, 2013).

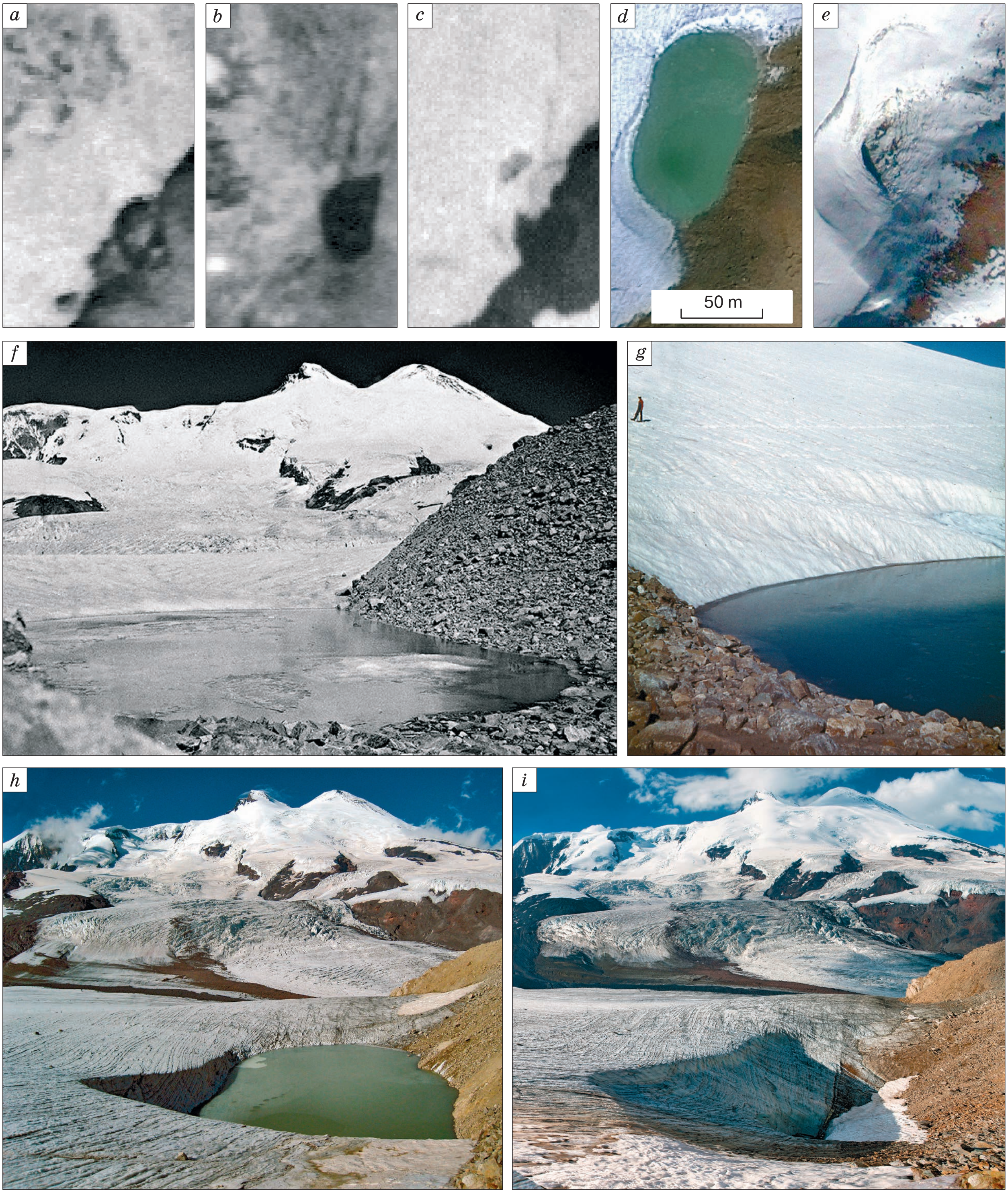

Fig. 7. Lake 15 on the Echo of War Passage:

(*a*) Aerial photo (Sept. 8, 1973), (*b*) aerial photo (Aug. 17, 1983), (*c*) aerial photo (July 27, 1988), (*d*) GeoEye-1 image (Sept. 19, 2009), (*e*) GeoEye-1 image (Oct. 16, 2009), (*f*) photo by V.F. Sukhomeilo (Aug. 29, 1973), (*g*) photo "uz89" (July 1985), (*h*) photo by Ya. Berezhko (Aug. 27, 2009), and (*i*) photo by Ya. Berezhko (Aug. 4, 2012).

180 m long. By May 18, its length reached 260 m, and the lake existed until June 14. In 2019, the lake appeared in mid-May and reached a length of 250 m by early June (Fig. 5*c*). In July, the lake was relatively small and disappeared at the end of the month. In 2020, satellite images made in May were unsuitable for lake detection because of the high cloudiness. In June 2020, the length of the lake reached 150 m; on July 8, 180 m. On July 11, the lake disappeared. In 2021, in May–June, satellite images were cloudy; at the end of June, the lake reached a length of 200 m; on July 8, it disappeared.

Lake at the Echo of War Passage (no. 15)

The lake existed in September 1971 (satellite image KH-4B (Corona) as of September 20, 1971, area of 550 m^2). In 1973, it was recorded on a photo by V.F. Sukhomeilo from August 29 (Fig. 7*f*) and on the aerial photo from September 8 (Fig. 7*a*, 630 m^2). In 1983, in an aerial photo on August 17, the area of the lake reached 770 m^2 (Fig. 7*b*). The lake was seen in July 1985 (Fig. 7*g*) and was absent in 1988 (Fig. 7*c*). There were no signs of its existence on the orthophotomap of 1997. The maximum area of 454 000 m^2 was determined from the satellite image of July 20, 2007, when a powerful surface runoff from the lake was seen. On March 31, 2009, there were no signs of the lake on the photo taken by Ya. Berezhko. In 2009, the lake was seen on the photos by Ya. Berezhko made on August 27, 29, and 30 and on a satellite image from September 19 (Fig. 7*d*). No signs of the lake were reveled on the satellite image as of October 16, 2009 (Fig. 7*e*). On July 30, 2010, the lake was seen on the Landsat-5 satellite image; on the image from August 8, it was absent. It was not absent on the photo taken by Ya. Berezhko on August 23, 2010. The lake cannot be seen on subsequent satellite images and photos. The approximate volume of the lake in 2009 in comparison with the topographic map of 2012 was 18 000–20 000 m^3, the depth was about 10 m.

DISCUSSION AND CONCLUSIONS

The conducted study made it possible to identify glacier lakes that existed in different periods near the Bolshoy Azau Glacier and on the glacier itself. The parameters of their long-term and seasonal dynamics were determined and compared to those of other lakes in different regions. Based on the data obtained, the following conclusions were made:

1. The areas of the identified lakes are small: up to 1000 m^2 – 4 lakes; 1000–5000 m^2 – 7 lakes; 5000–10 000 m^2 – 2 lakes, and more than 10 000 m^2 – 2 lakes. Based on the area of the lakes, the risks of lake breakthrough have been assessed differently. Thus, according to [*Rinzin et al., 2021*], the minimum threshold for the area of outburst-prone lakes is 50 000 m^2. For lakes smaller than 50 000 m^2, the breakthrough hazard index is low. In the new catalog of glaciers in Russia [*Khromova et al., 2021*], glacial lakes are considered hazardous, if their area is more than 5000 m^2. According to these criteria, four lakes (nos. 11–14) can be classified as hazardous.

2. According to the location relative to the glacier, the identified lakes can be classified as periglacial (at a distance of up to 2 km from the glacier, lakes 1–3, 5–8), proglacial (at the contact with the glacier, lakes 10, 15), and supraglacial (on the surface of the glacier or dead ice, lakes 4, 9, 11–14). At the initial stage of formation, lakes 5–9 were proglacial.

3. According to the type of dams, the lakes can be classified into the following groups: moraine–rock bar dams (lakes 1–3, 5–8), ice dams (lakes 10, 15) typical of periglacial and proglacial lakes, and snow-ice dams (lakes 4, 9, 11–14) typical of supraglacial lakes. Moraine-rock bar dams are resistant to erosion and slumping. Dynamics of the lakes bounded by them is determined by the balance of water inflow due to liquid precipitation in the catchment area, snow and ice melting, and water outflow from the basins through underground drainage channels. This explains the disappearance of lakes in the fall-winter period, when the filtration of water through the bottom of the lakes continued in the absence of water inflow into the basins.

Ice dams of proglacial lakes prevent the flow of water from the lakes until subglacial flow channels are formed, which leads to the disappearance of lakes in the fall-winter period. This was observed for lake 15: it was not found in March 2009 on the photo taken by Ya. Berezhko, but in the summer the lake reappeared (satellite image from September 19, 2009). Subsequently, with the retreat of the glacier to lower altitude levels and a decrease in its thickness, the basins of proglacial lakes and 15 were leveled and the lakes no longer appeared on the surface. Lake 15 passed through the stage of an increase in the mass balance of the glacier (in the late 1980s–mid-1990s), and the basin was filled with ice.

Snow-ice dams were formed annually at supraglacial lakes 9, 11, 13, and 14. The lakes existed in May–June, when the snow cover was still preserved until the snow-ice dams were eroded by concentrated flows of meltwater or melted. Before that, there was a period (as the dynamics of young lake 13 indicates), when a funnel was formed on the surface of the glacier as a result of ice subsidence. During this period, the outflow from the lake took place through the underground drainage channel; surface runoff through the glacier also developed. In this period, lake 13 existed in the second half of the summer (2019–2020). Supraglacial lake 12 has an ice dam, but the underground drainage channel can be blocked by seasonal snow-ice or debris masses slipping from the slopes of its basin.

4. The development of supraglacial lakes and their outbursts are characterized in studies of ice sheet lakes in Greenland and Antarctica [*Legleiter et al., 2014; Corr et al., 2022; Dirscherl et al., 2021*], as well as of glacier lakes in the Himalayas, Tibet, and other mountainous regions, including the outburst of a supraglacial lake with a volume of more than 1 million m^3 on the Halji Glacier in the Limi Valley (Nepal) [*Kropácek et al., 2015*]. The number of supraglacial lakes on one glacier can be very significant. For example, on the Chapdara Glacier in the basin of the Gunt River in the Pamirs, the authors identified more than 140 supraglacial lakes, the largest of which had an area of about 8000 m^2.

5. According to [*Kutuzov et al., 2019*], in the part of the Bolshoy Azau Glacier, where lakes 12–14 exist, the ice thickness exceeds 100 m. In this area, a re-deepening of the subglacial relief was observed [*Lavrentyev et al., 2020*], where the development of a subglacial lake is quite possible. Moreover, ongoing degradation of a glacier could also produce a large lake on the surface of the residual dead ice. In this regard, the appearance of supraglacial lakes of a larger size compared to the existing lakes can be supposed. Their outbursts might be cascaded, involving water masses from several supraglacial and subglacial lakes in the outburst flood. In this context, it is expedient to continue satellite monitoring of glacial lakes, conduct ground-based georadar studies of the glacier, and model possible outburst floods.

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